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SKINNER LANDFILL

FINAL SOIL VAPOR EXTRACTION SYSTEM FEASIBILITY INVESTIGATION

WEST CHESTER
BUTLER COUNTY, OHIO

PREPARED BY:

RUST ENVIRONMENT &
INFRASTRUCTURE INC.

11785 HIGHWAY DRIVE
SUITE 100
CINCINNATI, OHIO 45241
(513) 483-5300

AUGUST 1995

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August 7, 1995

Revision 1

Skinner Landfill
Soil Vapor Extraction
System Feasibility Investigation

Prepared by: Rust Environment & Infrastructure Inc.
11785 Highway Dr., Suite 100
Cincinnati, Ohio 45241
on behalf of the Skinner Landfill PRP Group

Date: August 7, 1995

Approvals: Jamey Bell Date 12/13/95

Jamey Bell
U.S. EPA Remedial Project Manager

Larry I. Bone Date 10/3/95

Larry I. Bone, Ph.D.
PRP Group Technical Committee Chairman
Dow Chemical Company

Edward C. Copeland Date 9/21/95

Edward C. Copeland, P.E.
Technical Project Manager for the PRP Group
Rust Environment & Infrastructure Inc.

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LIST OF ACRONYMS/ABBREVIATIONS

AOC	Administrative Order on Consent
ASTM	American Society for Testing and Materials
C_c	Coefficient of Curvature
cfm	Cubic Feet Per Minute
C_u	Coefficient of Uniformity
FI	Feasibility Investigation
IRM	Interim Remedial Measures
LL	Liquid Limit
MSL	Mean Sea Level
OEPA	Ohio Environmental Protection Agency
PI	Plasticity Index
PRP	Potentially Responsible Party
RDWP	Remedial Design Work Plan
Rust	Rust Environment & Infrastructure
RI	Remedial Investigation
ROD	Record of Decision
SOW	Statement of Work
SVOC	Semi-Volatile Organic Compounds
SVE	Soil Vapor Extraction
USCS	Unified Soils Classification System
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VOC	Volatile Organic Compounds

EXECUTIVE SUMMARY

In accordance with the requirements of the *Administrative Order on Consent (AOC)* between the United States Environmental Protection Agency (USEPA) and the Skinner Landfill Potentially Responsible Party (PRP) Group dated March 29, 1994, a field evaluation and proposal for Soil Vapor Extraction (SVE) have been performed. This work was completed in accordance with the *Statement of Work* for Remedial Design, Skinner Landfill Site, Butler County, Ohio and the *Remedial Design Work Plan* dated August 25, 1994.

The Skinner Landfill site is located approximately 15 miles north of Cincinnati, Ohio near the city of West Chester. The site was used in the past for sand and gravel mining, and was operated from approximately 1934 through 1990 to landfill a wide variety of materials. According to EPA studies, materials deposited at the site include demolition debris, household refuse, and a broad range of chemical wastes. Past field investigations have revealed that contamination was found at the buried waste lagoon. This report presents the results of the buried lagoon SVE System Feasibility Investigation (FI) performed at the Skinner Landfill Site.

The SVE System FI consists of three parts:

1) Buried Lagoon (Perimeter) Soils Investigation
2) Geotechnical Laboratory Analysis
3) Evaluation of Soil Vapor Extraction Feasibility

The following information summarizes the investigative methods, findings and recommendations of the SVE System FI.

<u>Buried Lagoon (Perimeter) Soils Investigation</u>

1. Subsurface Investigation - Buried Lagoon Perimeter
   a. Seven test borings were installed in October 1994.
   b. The static water table was observed at approximately 18 to 27 feet below ground surface.
   c. Two distinct soil zones have been defined:
      1. Beneath lagoon - silty clay (prior investigation)
      2. Lagoon perimeter - sandy loam

      These findings indicated that two contrasting permeabilities were observed.

2. Soil samples were submitted for the following geotechnical analyses:
   a. Sieve Analysis
   b. Atterberg Limits
   c. Moisture Content
   d. Organic Carbon Content
   e. Classification

Geotechnical Laboratory Analysis

1. Sieve Analysis findings indicated that well-graded sediments were present at the perimeter of the lagoon. This means that soil particles cover a wide range of diameters from very fine to very coarse. With this range of particle sizes, void spaces are filled with fine grained materials, thus decreasing porosity and limiting the effectiveness of vapor flow for an SVE remedial system.

2. Atterberg Limits testing results showed that soils on the perimeter of the lagoon include silty clays, clayey silts, and clayey sands. This test is mainly used to evaluate clay soils. The data indicate that very fine particles are present in the SVE zone, which would hamper remediation.

3. Moisture Content results indicated an average moisture content of 5.4 percent. A general range of moisture content is from 10 to 20 percent. Typically, the greater the moisture content the slower contaminant removal rates will be.

4. Organic Carbon Content testing results showed a geometric mean organic carbon content of 3.4 percent. Soils with an organic carbon content of more than 1 percent have a high sorption capacity for volatile organic compounds (VOC). This means the potential effectiveness of SVE will be reduced.

5. Two soil classification test results showed that the sediments on the perimeter of the buried lagoon are well graded, ranging from fine- to coarse-grained sediments. According to USCS particle size distribution charts, test results indicated that the buried lagoon perimeter soils are mainly silts and clays. According to the USDA classification system, the sediments tested were considered a sandy loam. For both classification schemes, this means that the fine-grained sediments found in the perimeter area will have low porosity, thereby decreasing void spaces, and limiting SVE effectiveness.

Evaluation of Soil Vapor Extraction Feasibility

1. *MODFLOW* Computer Software Applications and Findings
   a. *MODFLOW* was used to evaluate the performance of an SVE system installed in the permeable soils around the west, south, and east perimeter of the buried lagoon.
   b. Modeling was performed for transient conditions of 50 and 500 days.
   c. *Surfer* software was used to contour the radius of influence and vacuum conditions.
   d. A *MODFLOW* runtime equal to 500 days yields:
      Q (flowrate) = 160 cubic feet per minute (cfm)
      Vacuum = 10 feet of water (ft H_2O)
      Radius of influence $\leq$ 30 feet

e. To effectively remediate the buried lagoon, an SVE system located along the lagoon perimeter would require a radius of influence ≥ 75 feet to remove contaminants.

2. *HyperVentilate* Computer Software Applications and Findings
   a. Due to the ineffectiveness of a perimeter-based remedial approach, Rust investigated an approach assuming SVE wells would be placed in the silty clay zone of the buried lagoon. A computer software package called *HyperVentilate* was used to determine the number of extraction wells required if the SVE wells were installed <u>within</u> the buried lagoon. This determination evaluates the ease (or difficulty) of creating adequate air flow within the buried lagoon soils.
   b. The evaluation indicated that a minimum of 84 SVE wells would be required in the buried lagoon.
   c. Further, the evaluation indicated that a minimum of 32 SVE wells would be required in the perimeter soils for containment.

<u>Rust's Conclusions and Recommendations</u>

Attempting to remediate the buried lagoon contamination by applying SVE technology to the more coarse grained perimeter soils is not feasible because adequate air flow through the contaminated zone can not be achieved with this approach. Factors precluding effective air flow include:

1. Topography constraints - Because the ground surface on the outside of the perimeter (i.e., the "clean" side) slopes away from the SVE system, there will be less resistance to air flow; consequently, there will be more air flow coming from the perimeter and less from the lagoon (i.e., the target remediation zone).
2. Permeability contrasts - Because there is a permeability contrast of 3 to 4 orders of magnitude between the buried lagoon soils and the lagoon perimeter soils, the tendency for air to flow into the system from the contaminant zone (i.e., from the buried lagoon) will be minimized.
3. Effects of other remedial actions - Because the buried lagoon will be capped, there will be even greater resistance to air flow through the target remediation zone, further hindering remediation. In addition, the cap and the groundwater interception system will combine to create an effective method to capture and contain contaminants, obviating the need for the SVE system as a containment measure.

In addition to these effects, the relatively high organic carbon content of the soil will have a high adsorption capacity for the VOCs within the subsurface, thereby further inhibiting the effectiveness of SVE.

No further evaluation of soil vapor extraction for remediation of the buried lagoon soils is recommended.

1.0 INTRODUCTION

This report presents the results of the Soil Vapor Extraction (SVE) System Feasibility Investigation (FI) performed at the Skinner Landfill Superfund Site, West Chester, Butler County, Ohio. The FI was performed in accordance with the requirements of the Administrative Order on Consent (AOC) for Remedial Design for the Skinner Landfill Site between the U.S. Environmental Protection Agency (USEPA) and the Skinner Landfill Potentially Responsible Party (PRP) Group, dated March 29, 1994. The AOC presented selected investigative actions for the site and the requirements for report presentation. Attachments to the AOC included the Record of Decision and the Statement of Work, which will be discussed in Section 2.0.

Rust Environment & Infrastructure (Rust) completed the FI in three tasks. The first activity involved installing of seven soil borings around the perimeter of the buried lagoon. The second activity consisted of detailed geotechnical testing of representative soil samples collected from these borings. The final activity was to evaluate the performance of possible SVE systems using *MODFLOW* and *HyperVentilate* computer software. The FI was performed in accordance with the approved Remedial Design Work Plan submitted by Rust on August 25, 1994, and companion documents, Remedial Design Field Sampling Plan, Remedial Design Investigations Quality Assurance Project Plan, and Remedial Design Investigations Health and Safety Plan.

The remainder of this section of the FI presents descriptions and background information about the Skinner Landfill site. The project scope, objectives and the purpose of this investigation are discussed briefly in Section 2.0. Section 3.0 addresses the first part of the investigation, while Section 4.0 presents the geotechnical findings. SVE computer simulations are addressed in Section 5.0, which discusses computer software applications and findings. Conclusions and recommendations are presented in Section 6.0.

1.1 SITE LOCATION AND DESCRIPTION

The Skinner Landfill site is located approximately 15 miles north of Cincinnati, Ohio near the city of West Chester, an unincorporated area in Union Township, Butler County, Ohio, as shown in Figure 1. The Skinner site is comprised of approximately 78 acres of hilly terrain. The site is bordered on the south by the East Fork of Mill Creek, on the north by wooded, undeveloped land, on the east by a Consolidated Railroad Corporation (Conrail) right-of-way, and on the west by Skinner Creek.

The site is located in a highly dissected area that slopes from a till-mantled bedrock upland to a broad, flat-bottomed valley that is occupied by the main branch of Mill Creek. Elevations on the site range from a high of nearly 800 feet above mean sea level (MSL) in the northeast to a low of 645 feet MSL near the confluence of Skinner Creek and the East Fork of Mill Creek. Both Skinner Creek and the East Fork of Mill Creek are small, shallow streams that flow to the southwest from the site toward the main branch of Mill Creek.

1.2 SITE HISTORY AND BACKGROUND

The site was used in the past for sand and gravel mining, and was operated from approximately 1934 through 1990 to landfill a wide variety of materials. According to EPA studies, materials deposited at the site include demolition debris, household refuse, and a broad range of chemical wastes. The waste disposal areas include a now-buried waste lagoon near the center of the site and a landfill. According to EPA studies, the buried lagoon was used for the disposal of paint wastes, creosote, pesticides, and other chemical wastes. The landfill area, located north and northeast of the buried lagoon, received predominantly demolition and landscaping debris.

In 1976, in response to a fire on the site and reported observations of a black, oily liquid in the waste lagoon, the Ohio Environmental Protection Agency (OEPA) began an investigation of the Skinner Landfill. Before the OEPA could complete this investigation, the Skinners covered the waste lagoon with a layer of demolition debris, thereby hindering the investigation. Trenches were eventually excavated into the buried waste lagoon, and black and orange liquids and a number of barrels of wastes were observed.

In 1982 the site was placed on the National Priority List by the USEPA based on information obtained during a limited investigation of the site. In 1986 a Phase I Remedial Investigation (RI) was conducted that included sampling of groundwater, surface water, and soil as well as a biological survey of the East Fork of Mill Creek and Skinner Creek. A Phase II RI was conducted from 1989 to 1991 and involved further investigation of groundwater, surface water, soils and sediments. The Phase II RI also included investigation of the buried lagoon by means of soil borings drilled through the overlying construction/demolition debris and into the underlying native soils.

The field investigations have revealed that the most contaminated medium at the site is the soil from the buried waste lagoon. Lower levels of contamination were also found in soils on other portions of the site and in the groundwater, and low levels were found in the sediments of East Fork of Mill Creek, Skinner Creek, and the Duck and Diving Ponds. Migration of the contaminants has been limited, and the Phase II RI concluded that there had been no off-site migration of contaminants via groundwater. In accordance with the December 9, 1992 AOC for Interim Remedial Measures (IRM), groundwater samples are being obtained and analyzed quarterly. In addition, a fence was installed around the Skinner Landfill site and is inspected on a continuing biweekly basis.

1.3 GENERAL SOIL VAPOR EXTRACTION TECHNOLOGY DESCRIPTION

The SVE process is an in-situ technique for the removal of volatile organic compounds (VOC) and some semi-volatile organic compounds (SVOC) from the vadose zone of the soil. The vadose zone is the subsurface soil zone located between the surface soil and the top of the water table. SVE is commonly used with other technologies in a treatment train, since it transfers contaminants from soil to air and water wastestreams.

SVE treatment is conducted as follows. Vapor extraction wells or vents are installed in the unsaturated zone of a contaminated site. A vacuum is applied to the wells, usually supplemented by the injection of ambient air through separate wells. When the air passes through the soil, contaminants are volatilized and removed via vacuum extraction wells. Entrained liquids are separated from the air stream and the liquids are treated to remove contaminants. The gas is then drawn through a blower, treated (if necessary) and discharged to the atmosphere.

The two primary limiting factors when considering use of SVE is the volatility of the contaminants and the properties of the soil. SVE is most effective at removing compounds which have high vapor pressures and which exhibit significant volatility at ambient temperatures in contaminated soil. The air permeability of the contaminated soils controls the rate at which air can be drawn through the soil by the applied vacuum. This is generally related to the grain size of the soil, with sandy soils having a higher air permeability, while clayey or silty soils are less permeable. The soil moisture content or degree of saturation is also important. Soil heterogeneities will also limit effectiveness due to differential treatment and development of preferential pathways.

2.0 PROJECT SCOPE AND OBJECTIVES

As documented in the *Record of Decision (ROD)*, it was suggested during the public comment period that "extraction of the volatile organic vapors from the permeable materials surrounding the lagoon wastes be considered as a remedial alternative." It was this suggestion which initiated the SVE System FI.

The *Statement of Work (SOW)* indicated that the primary objective of the SVE System FI is to determine the practicality of an SVE system removing organic vapors within the "permeable" perimeter materials adjacent to portions of the buried waste lagoon. The perimeter areas along and adjacent to the western, southern, and eastern boundaries of the buried waste lagoon area were to be investigated.

The *Remedial Design Work Plan (RDWP)*, submitted by Rust on August 25, 1994, indicated that Phase I would consist of three primary tasks: soil borings, geotechnical laboratory testing, and the comparison of findings with published literature. The scope of subsequent phases of investigations would depend on the results of the Phase I investigation.

The Phase I field investigation for the FI consisted of seven borings drilled on the perimeter of the buried waste lagoon. The purpose of the borings was to determine the vertical and lateral distribution of granular materials adjacent to the buried lagoon. Selected soil samples from the borings were tested in a geotechnical laboratory to determine their gradation characteristics, moisture content and organic carbon content. In addition to a limited data search, the results of the laboratory tests were used in computer models to determine if SVE would be a practical technology for the remediation of buried lagoon volatile contaminants.

This document is intended to report methods, findings and conclusions of the Phase I investigation As discussed in the *RDWP*, if the findings of the investigation indicate that an SVE system may be a viable method to remove organic vapors from the granular materials adjacent to the buried waste lagoon, the report will contain recommendations and proposals for additional work that may be required in subsequent phases to further evaluate and design an SVE system. If the findings of the investigation are that an SVE system is not feasible, the report will recommend that no further action be taken with respect to SVE.

The *SOW* established a May 23, 1995 submittal date for the completion of a draft report on the SVE System FI.

3.0 SUPPLEMENTAL INVESTIGATION ACTIVITIES

As defined in the approved *RDWP*, the purpose of the supplemental field investigation was to obtain additional data for evaluating the feasibility of an SVE system for the removal of organic vapors within the soils adjacent to the buried waste lagoon. The perimeter areas along and adjacent to the western, southern and eastern boundaries of the buried waste lagoon area were investigated. Supplemental site investigation activities began in November 1994 under the direction of Rust personnel. During the course of this investigation, Rust employees installed a series of on-site test borings and submitted representative soil samples for geotechnical testing. Field investigation tasks were conducted in accordance with the requirements of the OEPA and USEPA.

3.1 SUBSURFACE INVESTIGATION - BURIED LAGOON PERIMETER

The supplemental field efforts consisted of evaluating the subsurface materials to identify the nature and extent of potential SVE applications. Seven soil borings were installed along the perimeter of the buried waste lagoon to determine the physical characteristics, areal extent and uniformity of sediments. Locations of these borings are shown in Figure 2. The depths of borings varied from depths of 14 to 42 feet below grade. Descriptions of the subsurface materials are presented in the Soil Borehole Logs contained in Appendix A. Continuous soil samples were obtained in accordance with American Society for Testing and Materials (ASTM) Methods.

3.2 GEOTECHNICAL LABORATORY ANALYSES

Soil samples were obtained for geotechnical testing to determine whether or not the subsurface sediments are conducive to SVE applications. Each soil sample collected was properly logged in the field and classified in accordance with the Unified Soil Classification System (USCS). Analyses for complete grain size, Atterberg Limits, and moisture content were performed on one representative sample from each designated test boring location. All geotechnical analyses were conducted in accordance with appropriate ASTM standards. The depth of these samples was selected in a range below the contamination and above the water table. The samples were collected at the depths where the SVE well screens would actually be open and at which the vacuum would actually be applied. Typically, a SVE well point is constructed with a screened interval near the bottom of the well (but above the water table) so that air is drawn from the ground surface downward through the entire vadose zone. As such, the geotechnical data at the bottom of the anticipated well point are of interest because this defines the zone of influence the well will create. The following table indicates the depths at which each sample was obtained:

Test Boring	B-59	B-61	B-62	B-63	B-64	B-65	B-66
Sample depth (ft)	14-16	10-12	14-16	16-20	18-22	18-22	16-18

4.0 SUPPLEMENTAL INVESTIGATION FINDINGS

On November 11, 1995, after completing field activities, seven soil samples were submitted for geotechnical analyses. The soil sample test record, as shown below, indicates the analyses performed. The analytical findings from these tests are summarized in Table 1 and consist of the following parameters:

- Sieve Analysis - ASTM D422
- Atterberg Limits - ASTM D4318
- Moisture Content - ASTM D2216
- Organic Content - ASTM D2974
- Classification - ASTM D2487

Sieve Analysis

A sieve analysis is performed when a sample of dry soil is shaken mechanically through a series of woven-wire square-mesh sieves with successively smaller openings. The sieve analysis is useful in determining grain-size distributions (i.e., grading), as well as the coefficient of uniformity and coefficient of curvature. The Skinner soil samples tend to be characterized as well-graded sand, silt and clay; the grain size distribution reports are shown in Appendix B.

The coefficient of uniformity (C_u) indicates the smaller the number, the more uniform the gradation. For example, a $C_u = 1$ is indicative of a soil with only one grain size. Very poorly graded soils, such as beach sands, have C_u values of 2 or 3, while very well-graded soils may have C_u values of 15 or greater. C_u values equal to or greater than 500 typically represent a range of particle sizes from cobbles and boulders down to fine clays.

Another shape parameter that is often used for soil classification is the coefficient of curvature (C_c). A soil with a coefficient of curvature between 1 and 3 is considered to be well graded as long as the C_u is also greater than 4 for gravel and 6 for sand. Description of C_c and C_u formulas are shown in Appendix C.

The following table represents C_u and C_c geotechnical findings from the buried lagoon supplemental test borings:

Gradation Parameter	B-59	B-61	B-62	B-63	B-65	B-66
C_u	N.A.*	767.4	645.7	841.4	720	2660
C_c	N.A.*	55.6	8.1	1.6	0.6	3.2

*Note: See Appendix C for appropriate equations used in the calculation of C_u and C_c.
N.A. indicates that no value for D_{10} was obtained, thus no calculation was completed.

The geometric mean for C_u and C_c were determined using the following calculations:

$$C_u = ((767.4)(645.7)(841.4)(720)(2660))^{1/5} = 956.0$$

while $$C_c = ((55.6)(8.1)(1.6)(0.6)(3.2))^{1/5} = 4.2$$

These values indicate that the soils along the perimeter of the buried lagoon are non-uniform (i.e., they have a wide range of grain sizes) and moderately well-graded (i.e., the proportion of each grain size is approximately equal and varies smoothly). Soils with these characteristics typically have a relatively low porosity and low permeability because the voids between the larger particles are filled in by the smaller ones. Soils with low porosity and low permeability typically represent a poor environment for soil venting.

Atterberg Limits

The Atterberg limits indicate the engineering behavior of fine-grained soils as a function of water content in soil samples. The Atterberg limits, along with the natural water content, are important items in the description and behavior of fine-grained soils. Typically Atterberg limits are helpful in classifying soils, because they correlate with the engineering properties of fine-grained soils.

Two Atterberg limit parameters were evaluated from the lagoon perimeter test borings. The parameters were the Lower Limit (LL) and the Plasticity Index (PI). The PI is the range of water content where a soil is plastic, while the LL is the lower limit of viscous flow. The PI and LL are plotted on a Casagrande's Plasticity Chart which is used for laboratory classification of fine-grained soils. A geometric mean obtained for the LL is 20.8, while the PI geometric mean equals 6.0. The following table indicates the values obtained for each appropriate sample:

Soil Boring	B-59 (14-16')	B-61 (10-12')	B-62 (14-16')	B-63 (16-20')	B-65 (18-22')	B-66 (16-18')
Liquid Limit (LL)	20.4	23.0	20.2	19.2	20.0	22.5
Plasticity Index (PI)	6.8	6.3	4.9	4.9	6.2	7.3

By plotting these two parameters on Casagrande's Plasticity Chart, they indicate that the Skinner borings are "Silty clays; clayey silts and clayey sands." An example of Casagrande's chart, with an indication of the Skinner LL and PI placement, is shown in Appendix E.

Moisture Content

Another significant soil characteristic is the mass of water in the voids relative to the mass of solids in the soil. Typically, the greater the moisture content the slower contaminant removal rates will be. The ratio of water mass to soil mass is called the moisture content. The geometric mean moisture content for the lagoon perimeter borings is 5.4 percent. Typically, soils exhibit a moisture range of 10 to 20 percent. Since this moisture content of 5.4 percent is fairly low, it doesn't appear to be a constraint to SVE applications.

Organic Carbon Content

According to C.W. Fetter's Contaminant Hydrogeology (Prentice-Hall, 1981), many organic compounds which are dissolved in groundwater can be adsorbed onto solid surfaces. The primary adsorptive surface is the fraction of organic solids in the soil. The partitioning of a solute onto the organic carbon content of a soil is almost entirely onto the organic carbon fraction if the organic compound content is greater than 1 percent by weight. The following table indicates organic carbon values obtained for each appropriate sample:

Soil Boring	B-59 (14-16')	B-61 (10-12')	B-62 (14-16')	B-63 (16-20')	B-64 (18-22')	B-65 (18-22')	B-66 (16-18')
Organic Carbon	1.47 %	3.11 %	4.80 %	3.92 %	6.40 %	4.25 %	2.46 %

The geometric mean obtained from the supplemental soil borings yielded a value of 3.44 percent. Soils with a high organic carbon content have a high sorption capacity for VOCs and are more difficult to remediate successfully with SVE. It appears that an organic carbon content of 3.44 percent could have an impact on contaminant adsorption and hinder the effectiveness of a soil venting system.

Soil Classification

In an effort to fully assess the soil particle characteristics, two soil classification systems were used to evaluate the perimeter lagoon soils. The USCS classification was the first system to be reviewed, which indicated that a wide range of well-graded sediments was present. Materials ranged from gravel-sand-silt-clay mixtures to sand-silt-clay mixtures. These classifications were determined using sieve analysis data to quantify the appropriate particle sizes. Soils which cover this range of particle diameters will tend to minimize porosity and in effect, hinder the effectiveness of an SVE system.

A second classification system called the United States Department of Agriculture (USDA) Scheme was used to evaluate a group of soils classified as "soil separates," which are defined as particles less than 2 mm in diameter. The USDA scheme is based on plotting various combinations of sand, silt, and clay. Appendix D shows the triangular coordinate diagram, used in the evaluation of sand, silt and clay combinations, which gives a ratio of the three constituents.

The evaluation of the supplemental test boring samples was very consistent, with all samples being plotted as a sandy loam. According to the USDA definition, a sandy loam is a "soil material that contains 20 percent clay or less, the percentage of silt plus twice the percentage of clay exceeds 30, and 52 percent or more sand."

The designation of "sandy loam" (USDA) and gravel-sand-silt-clay mixture (USCS) for the buried lagoon perimeter samples indicates the soils around the lagoon are more coarse grained than soils within and below the lagoon. Sediments obtained from within the buried lagoon were characterized as silty clay during a prior lagoon investigation, which according to the USDA definition is a "soil material that contains 40 percent or more clay and 40 percent or more silt." Both the USCS and the USDA classification systems indicate that perimeter sediments range from gravel and sand to silts and clays. As previously mentioned, these well-graded perimeter soils typically are not conducive to SVE applications due to the limited void space.

5.0 SOIL VAPOR EXTRACTION FEASIBILITY ASSESSMENT

In-situ vapor extraction, or soil venting, is considered to be a cost-effective remediation alternative for permeable soils contaminated with volatile contaminants. Contaminants volatilize from the soil matrix and are swept by the carrier gas flow (air) to the extraction well, treated and discharged. The five main factors that control the effectiveness of a venting system are:

1. Chemical composition of the contaminant (i.e., applicable Henry's Law Constants).
2. Vapor flow rates through the unsaturated zone.
3. Pressure drop induced by applying a vacuum.
4. The flow path of carrier vapors relative to the location of the contaminants.
5. Soil characteristics (i.e., void space, moisture content, organic carbon content).

The following subsections present the SVE system evaluation. The soil venting was evaluated using the United States Geological Survey (USGS) *MODFLOW* program and *HyperVentilate*, a USEPA-endorsed software guidance system created for vapor extraction applications. The computer-based evaluations were performed to supplement the comparison of a literature search, as specified in the *RDWP*. This combined method provides more site-specific data and relevant information regarding the feasibility of SVE than a solitary data comparison.

5.1 MODFLOW APPLICATIONS AND FINDINGS

The *MODFLOW* software was used to determine the pressure drops within the subsurface soils at various radii following application of a known vacuum. The pressure distribution and shape of the area of reduced pressure indicates the potential performance of the system. Soil venting at the Skinner site was simulated using venting wells placed around the perimeter as discussed in the approved *RDWP*.

The modeling was performed under transient conditions with simulated durations of 50 and 500 days. As shown in Figure 3, a zone of 550 feet (length) and 70 feet (height) oriented along a west to east cross-section was used as a grid system for modeling purposes. Figure 3 also represents a cross-section of the topographic features observed at the buried lagoon site. Based upon a perimeter SVE system and the prior knowledge of contaminant location, it has been determined that an effective radius of greater than 75 feet is needed to reach the contaminant zone.

A contrast in permeabilities has been documented between the buried lagoon (silty clay - Zone 2) and the lagoon perimeter (sandy loam - Zone 1). This contrast, as shown in Figure 3, will have a significant impact on the performance of an SVE system. For modeling purposes, these two contrasting permeability zones are shown as being distinct with clear dividing lines. Based upon the calculations to estimate gas permeabilities, as shown in Appendix F, the two zones were given a gas permeability of 1.75×10^{-4} ft/day (Zone 2) and 1.75×10^{-2} ft/day (Zone 1). Soils exhibiting low air permeability are more difficult to treat with in-situ SVE technology. A specific storage of 0.02 was used for the simulation, indicating a moderate-to-low volume of air released due to subsurface porosity and permeability constraints. A constant head boundary of (-)0.167 feet of water was assumed for all boundary cells (except for the cells above the bedrock), indicating that these boundary cells will not have limited head constraints during *MODFLOW* simulations.

Modeling was performed by inducing a vacuum at two cells (i.e., SVE well locations) along the perimeter of the lagoon as shown in Figure 3 (i.e., row 3, column 13 and row 5, column 42). Flow rates were input as 1.0 and 2.0 cubic feet per minute (cfm) per foot width of the cross-section. This generates a two-well total flowrate of 80 cfm (scenario A) and 160 cfm (scenario B), respectively. The pressure drops calculated by *MODFLOW* were then contoured using the graphics software package *Surfer* to visually plot the effective radius of influence. The lateral pressure drop that occurs by applying a vacuum (ft H_2O) at a venting well is represented in Appendix G. This change in pressure defines the extent to which air flow will be induced through the contaminated soils.

The following table represents the *MODFLOW/Surfer* parameters and findings:

Scenario	Time (days)	Vacuum (ft H2O)	Flowrate (cfm)	Effective Radius (ft)
A	50	1	80	12.5
A	500	5	80	30
B	50	2	160	20
B	500	10	160	30

Based upon the data presented above and in Appendix G, which indicate the effective radius of influence and pressure drop, it appears that soil venting from the perimeter cannot create sufficient vacuum in the direction of the buried lagoon to the produce air flow needed to remove contaminants in the impacted zone. By reviewing Figure 3, which indicates the contrasting conductivities observed in the lagoon area and in the perimeter region, we can determine the limited effectiveness of an SVE system. At 500 days of operation for either scenario, an effective radius of 30 feet is indicated which will have no impact on the zone of contamination centered in the lagoon. However, if the SVE wells are applied as a containment remedy along the perimeter of the buried lagoon (See Figure 4), it is estimated that, based upon an effective radius of 30 feet and a lineal distance of 700 feet, 12 wells would be required.

5.2 HYPERVENTILATE SOFTWARE APPLICATIONS AND FINDINGS

To illustrate the difficulty of creating sufficient air flow within the buried lagoon soils, Rust used *HyperVentilate* to determine the number of extraction wells that would be required if an SVE system were to be placed within the buried lagoon.

HyperVentilate is intended to be used for evaluating SVE as a remediation alternative; it is not intended to be a detailed SVE modeling or design tool. Soil permeability and contaminant concentration data from prior investigations were used to develop a rough approximation of the system's desired and maximum removal rates. By using *MODFLOW* data regarding radius of influence and vacuum rates, it is possible to evaluate SVE applications.

Assuming that the model parameters described above adequately represent the chemical and flow dynamic behavior of the site, the venting model can provide a component-by-component and total contaminant depletion rate. While the model is capable of predicting the venting time to remove a particular volatile constituent, it is more important to compare the individual component depletion rates in a relative sense rather than in the absolute sense.

The data shown in Appendix H show how calculations and assumptions were addressed. The findings of the *HyperVentilate* model indicated that a minimum of 84 SVE wells would be needed to remediate the buried lagoon. To accomplish the remediation, wells would need to be installed into the buried lagoon itself. This presents a concern relative to installation and integrity of the low-permeability cap that will be installed as part of the Remedial Action. This number of wells would likely compromise the integrity of the cap, causing infiltration into the buried lagoon. This gives additional validation to the *MODFLOW* findings which indicate that SVE is not a practical approach to the buried lagoon site.

Hyperventilate was also used to evaluate the feasibility of installing the SVE wells along the perimeter of the buried lagoon as a containment measure. Based upon the calculations provided in Appendix H, it is estimated that approximately 32 wells would be required to provide a containment function. This is in contrast to the estimated 12 wells required based upon *MODFLOW* calculations. The difference can be identified in the underlying principles of the different softwares. *MODFLOW* was designed primarily to simulate hydrologic systems in the soil matrix. It has been modified to reflect air flow characteristics, but still is considered only an indicator of the potential for subsurface airflow, not as an SVE design tool. Likewise, *HyperVentilate* has certain limitations, including applicability for containment as opposed to remediation. However, it is believed that HyperVentilate reflects the required number of SVE wells more accurately than *MODFLOW*.

Regardless, it is believed that installation of 32 wells is not a practical application of SVE for containment. This argument is strengthened by the fact that the buried lagoon will be capped, and a groundwater interception system will be installed. These two measures effectively address containment of the buried lagoon. Installation of the SVE system would be unnecessarily redundant.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based upon the buried lagoon soils investigation, the geotechnical laboratory analysis and evaluation of the SVE applications, it appears that the buried lagoon site is not conducive to the use of SVE technology. Attempting to remediate the buried lagoon contamination by applying SVE technology to the more coarse grained perimeter soils would short circuit a remedial system due to topography constraints and permeability contrasts. Other parameters which will cause difficulties in remediation pertain to high organic carbon content, as well as the fact that the buried lagoon is scheduled to be capped, thus hindering air flow and remediation. The following summarizes the SVE System FI findings:

Geotechnical Laboratory Analysis

1. Sieve Analysis findings indicated that well-graded sediments were present at the perimeter of the lagoon. This means that soil particles cover a wide range of diameters from very fine to very coarse. With this range of particle sizes, void space are filled with fine grained materials, thus decreasing porosity and limiting the effectiveness of vapor flow for an SVE remedial system.

2. Atterberg Limits testing results showed that soils on the perimeter of the lagoon include silty clays, clayey silts, and clayey sands. This test is mainly used to evaluate clay soils. The data indicate that very fine particles are present in the SVE zone, which would hamper remediation.

3. Moisture Content results indicated an average moisture content of 5.4 percent. A moisture content range of 10 to 20 percent is considered normal. Generally, the greater the moisture content the slower contaminant removal rates will be.

4. Organic Carbon Content testing results showed a geometric mean organic carbon content of 3.4 percent. Soils with an organic carbon content of more than 1 percent have a high sorption capacity for VOCs. This means the potential effectiveness of SVE will be reduced.

5. Two soil classification test results showed that the soils on the perimeter of the buried lagoon are well graded, ranging from fine-to coarse-grained sediments. According to USCS particle size distribution charts, test results indicate that the buried lagoon perimeter soils are mainly silts and clays. According to the USDA classification system, the sediments tested were considered a sandy loam. For both classification schemes, this means that the fine-grained sediments found in the perimeter area will have low porosity, thereby decreasing void spaces, and limiting SVE effectiveness.

Evaluation of Soil Vapor Extraction Feasibility

1. *MODFLOW* Computer Software Applications and Findings:

a. *MODFLOW* was used to evaluate the performance of an SVE system installed in the permeable soils around the west, south, and east sides of the buried lagoon.
b. Modeling was performed for transient conditions of 50 and 500 days.
c. *Surfer* software was used to contour the radius of influence and vacuum conditions.
d. A *MODFLOW* runtime equal to 500 days yields:
   Q (flowrate) = 160 cfm
   Vacuum = 10 ft H_2O
   Radius of influence $\leq$ 30 feet
e. To effectively remediate the buried lagoon, an SVE system located along the lagoon perimeter would require a radius of influence $\geq$ 75 feet to remove contaminants.

2. *HyperVentilate* Computer Software Applications and Findings:
   a. Due to the ineffectiveness of a perimeter-based remedial approach, Rust investigated an approach consisting of SVE wells being placed in the silty clay zone of the buried lagoon using a computer software package called *HyperVentilate*. *HyperVentilate* was used to determine the number of extraction wells required if the SVE wells were installed <u>within</u> the buried lagoon. This determination provides a sense of the ease (or difficulty) of creating adequate air flow within the buried lagoon soils.
   b. The evaluation indicated a minimum of 84 SVE wells would be required in the buried lagoon.
   c. Further, the evaluation indicated that a minimum of 32 SVE wells would be required in the perimeter soils for containment.

<u>Rust's Conclusions and Recommendations</u>

Attempting to remediate the buried lagoon contamination by applying SVE technology to the more coarse grained perimeter soils is not feasible because adequate air flow through the contaminated zone can not be achieved with this approach. Factors precluding effective air flow include:

- Topography constraints - Because the ground surface on the outside of the perimeter (i.e., the "clean" side) slopes away from the SVE system, there will be less resistance to air flow, consequently, there will be more air flow coming from the perimeter and less from the lagoon (i.e., the target remediation zone).

- Permeability contrasts - Because there is a permeability contrast of 3 to 4 orders of magnitude between the buried lagoon soils and the lagoon perimeter soils, the tendency for air to flow into the system from the contaminant zone (i.e., from the buried lagoon) will be minimized.

- Effects of other remedial actions - Because the buried lagoon will be capped, there will be even greater resistance to air flow through the target remediation zone, further hindering remediation. In addition, the cap and the groundwater interception system will combine to create an effective method to capture and contain contaminants, obviating the need for an SVE system as a containment measure.

In addition to these effects, the relatively high organic carbon contents of the soil will have a high adsorption capacity for the VOCs within the subsurface, thereby inhibiting the effectiveness of SVE.

No further evaluation of soil vapor extraction for remediation of the buried lagoon soils is recommended.

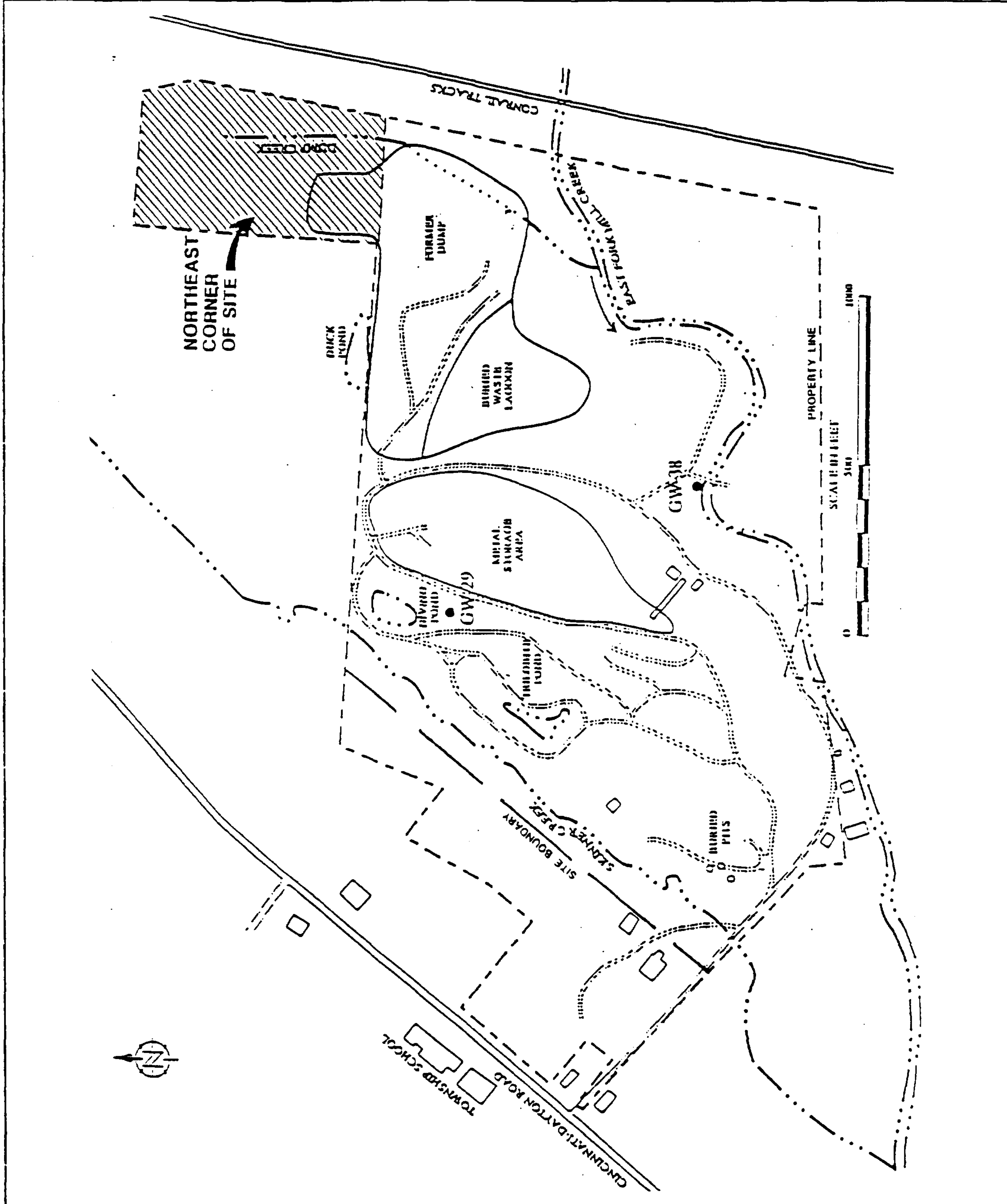

FIGURE 1
SITE LOCATION MAP
PROJECT 72680.300

SVE FEASIBILITY STUDY
SKINNER LANDFILL
WEST CHESTER, OHIO

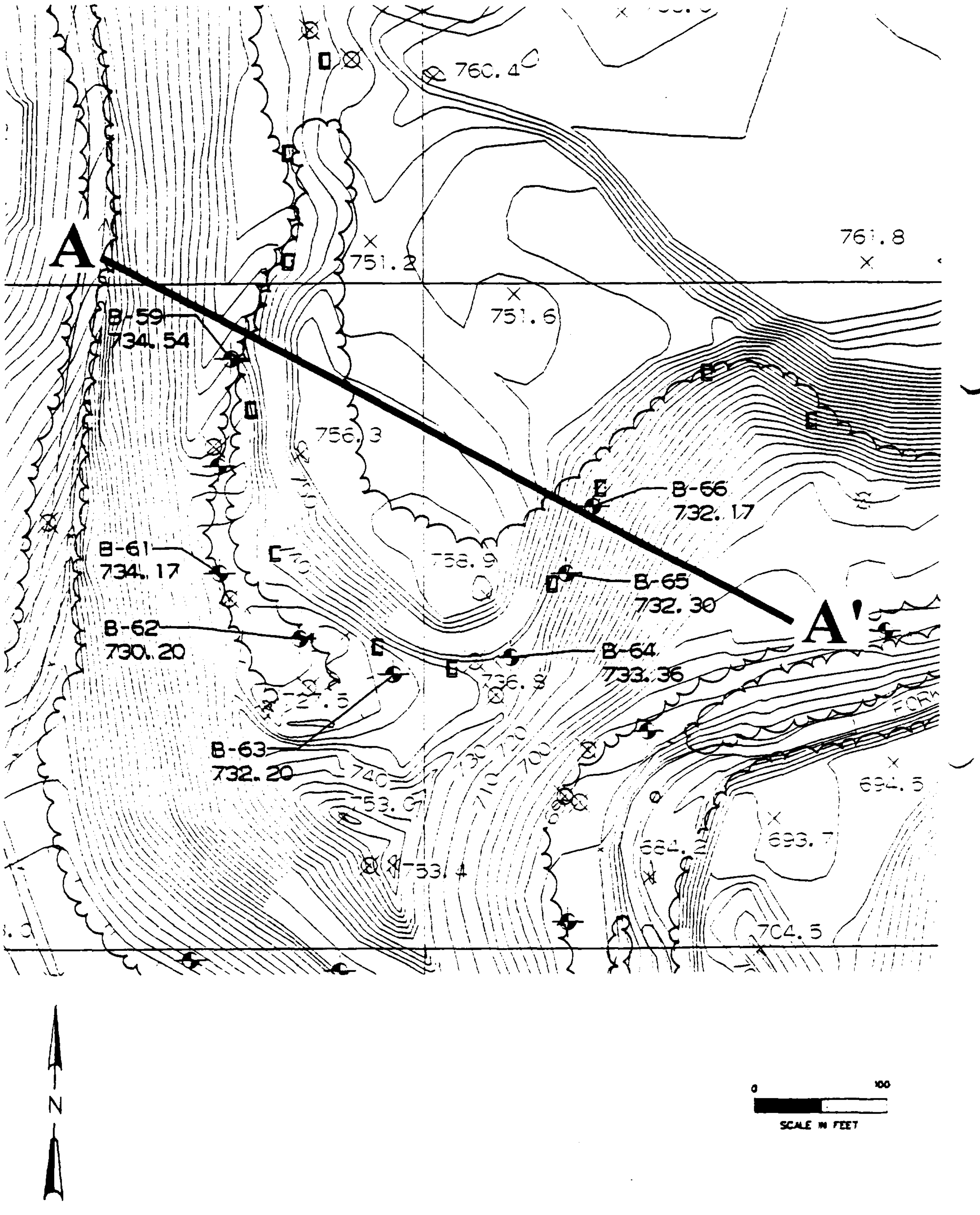

FIGURE 2
BURIED LAGOON TEST BORING
CONFIGURATION
PROJECT 72680.300

SVE FEASIBILITY STUDY
SKINNER LANDFILL
WEST CHESTER, OHIO

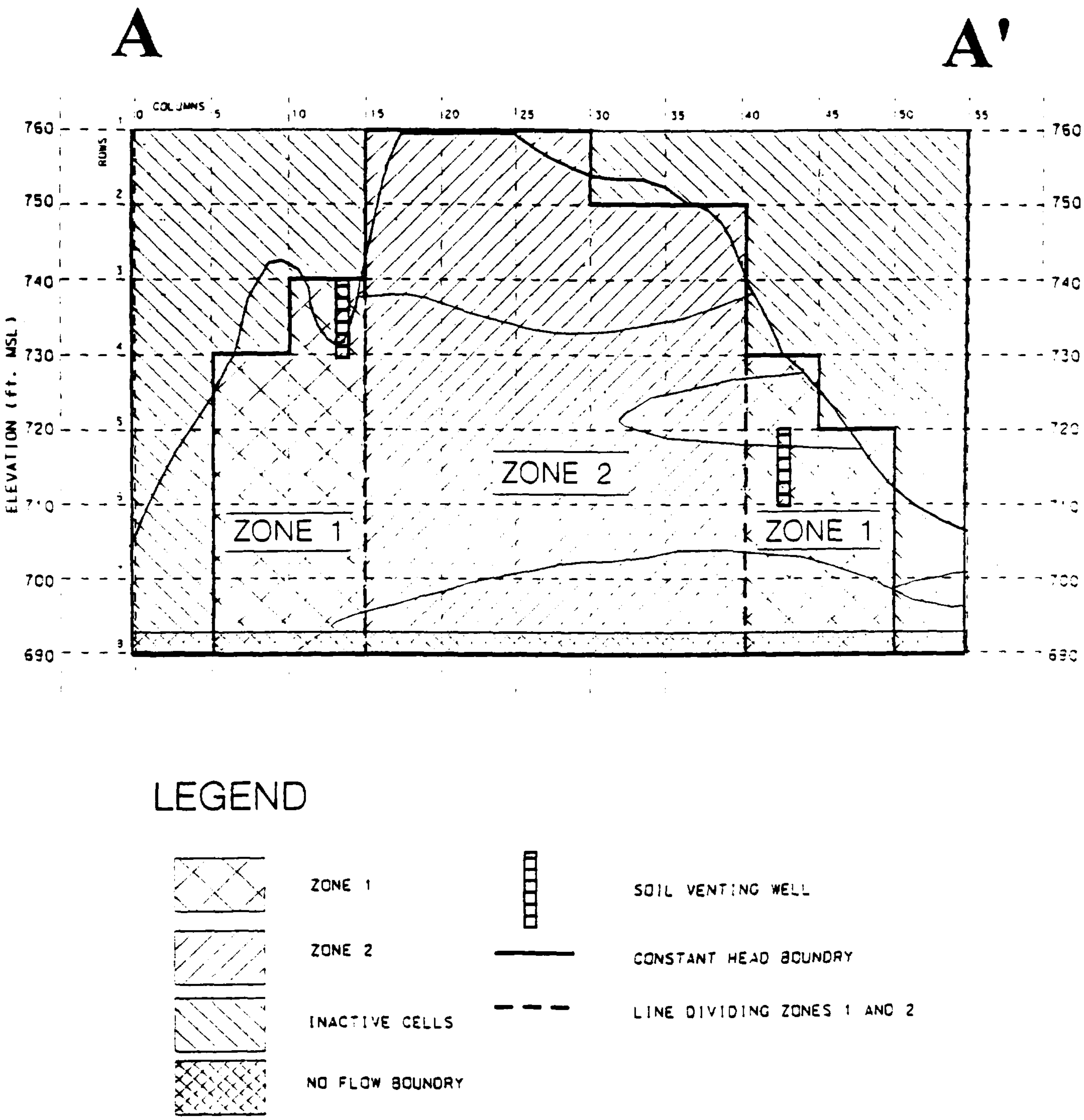

FIGURE 3 SOIL VENTING MODFLOW SIMULATION FINITE DIFFERENCE GRID SYSTEM PROJECT 72680.300	SVE FEASIBILITY STUDY SKINNER LANDFILL WEST CHESTER, OHIO

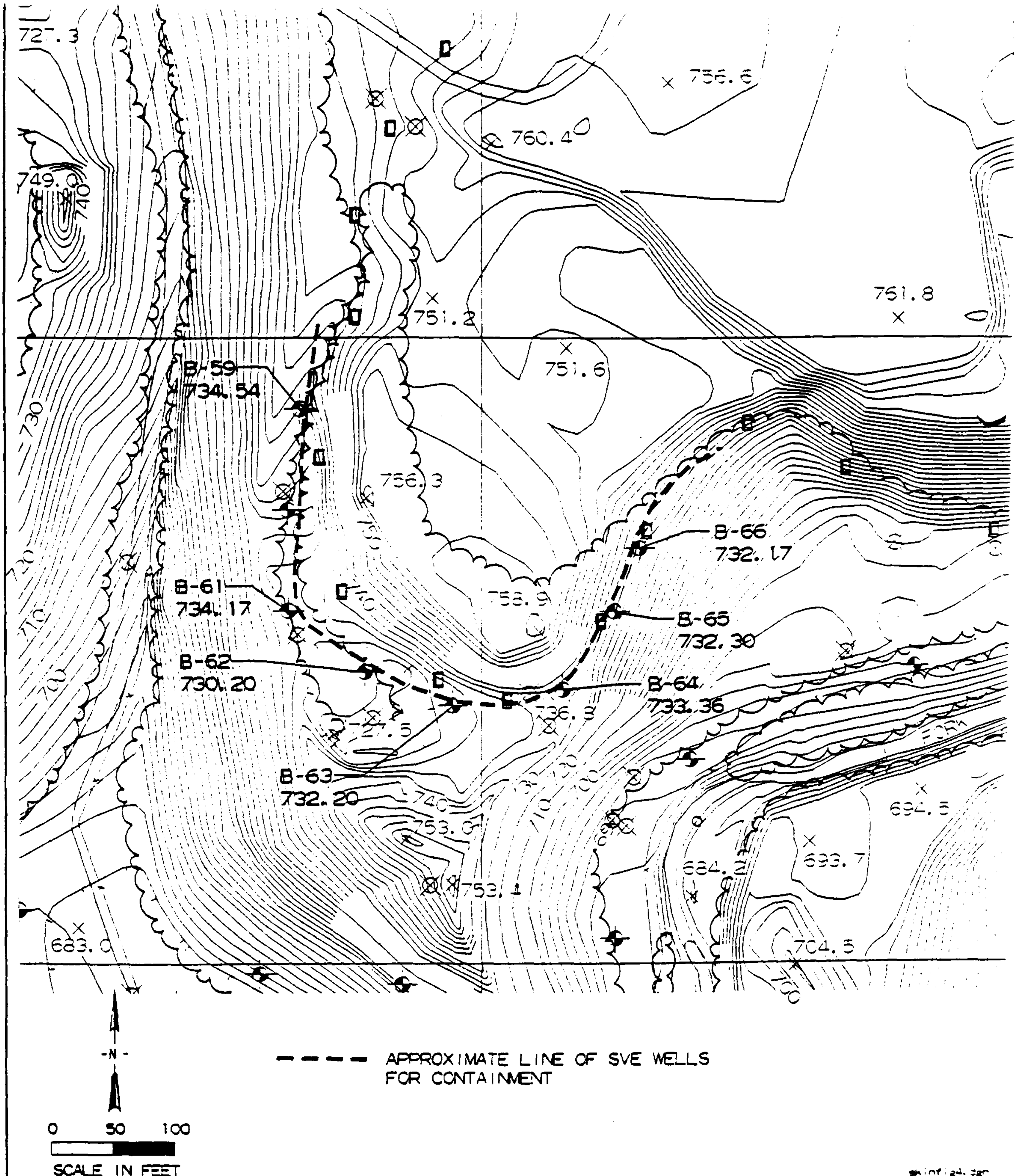

FIGURE 4
APPROXIMATE LINE OF
SVE WELLS FOR CONTAINMENT
PROJECT 72680.300

SVE FEASIBILITY STUDY
SKINNER LANDFILL
WEST CHESTER, OHIO

TABLE 1

GEOTECHNICAL ANALYSES RESULTS
Skinner Landfill
West Chester, Ohio

Boring ID	Sample Interval (ft BGS)	Laboratory Test (Method)	USCS Soil Classification	Soil Description	Moisture Content (%)	Percent Passing			Organic Carbon Content
						#10	#40	#200	
B-59	14 to 16	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	SC -SM	Brown and gray silty, clayey sand	9.5	78.2	62.5	44.3	1.47
B-61	10 to 12	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	GC - GM	Brown silty, clayey gravel with sand	2.8	27	19.5	14.7	3.11
B-62	14 to 16	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	GC - GM	Silty clayey gravel with sand	4.2	34.4	22.9	15.7	4.80
B-63	16 to 20	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	SC-SM	Brown silty, clayey sand with gravel	8.1	65	48.8	31.6	3.92
B-64	18 to 22	N/A	N/A	Yellow clay, silty w/ limestone fragments	N/A	N/A	N/A	N/A	6.40
B-65	18 to 22	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	SC - SM	Brown silty, clayey sand with gravel	7.2	65	52.3	35.5	4.25
B-66	16 to 18	Grain-Size (ASTM D422)/Mositure Content (ASTM D2216)	GC	Clayey gravel with sand	3.9	40.4	33	24.1	2.46

APPENDIX A

Soil Borehole Logs

SOIL BOREHOLE LOG

SITE NAME AND LOCATION: Skinner Landfill - West, Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-59	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 1 OF 2	
	WATER LEVEL	DRILLING	
	TIME	START TIME 1550	FINISH TIME 1655
NORTH / EAST	DATE	DATE 10-21-94	DATE 10-21-94
DATUM ft. msl / ELEVATION 735.02	CASING DEPTH		
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING -------			
SAMPLE HAMMER TORQUE / FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER	DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	11, 16, 10, 13, 18"		1	Light yellowish brown SILT (ML), damp, non-plastic, trace gravel, 30% sand, 10 % clay (FILL).	SS						
2–4	19, 14, 14, 14, 18"		2	Light yellowish brown SILT (ML), damp, non-plastic, trace limestone gravel, 20% clay, 10 % sand (FILL).	SS						
4–6	12, 14, 7, 8, 12"		3	Light yellowish brown CLAY (CL), moist, plastic, 20% silt, 10% sand (FILL).	SS						
6–8	38, 14, 12, 12, 12"		4	Light yellowish brown CLAY (CL), moist, plastic, 20% silt, 10% sand (FILL).	SS						
8–10	4, 7, 8, 8, 15"		5	Light yellowish brown CLAY (CL) moist, plastic, 20% silt, 10% sand. Light yellowish brown SAND (SW), wet, fine-grained, 15% sand, 15% clay.	SS						
10–12	6, 10, 7, 11, 6"		6	Gray CLAY (CL), moist, plastic, limestone fragments, 10% silt, 10% sand.	SS						
12–14	8, 50/1, 4"		7	Gray CLAY (CL), moist, plastic, limestone fragments, 10% silt, 10% sand.	SS						
14–15	10, 10, 15			Gray CLAY (CL), moist, plastic, limestone fragments, 10% silt.							

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DRILLING CONTR

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SOIL BOREHOLE LOG

SITE NAME AND LOCATION: Skinner Landfill - West, Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-59	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 2 OF 2	
		DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	1550	1655
NORTH / EAST	DATE	DATE	DATE
DATUM ft. msl / ELEVATION 735.02	CASING DEPTH	10-21-94	10-21-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING ------			
SAMPLE HAMMER TORQUE / FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
15	16 4"		8	SS						
16	50/1 0"		Weathered SHALE (SH) and fossiliferous LIMESTONE (LS) fragments. (Difficulty augering; no recovery. Drill cuttings observed for lithology).							
17			9	SS						
18			END OF BORING AT 18.0 FEET.							
19										
20										
21										
22										
23										
24										
25										
26										
27										
28										
29										
30										

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DRILLING CONTR

DATE 5/18/95

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SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-61	
		SHEET 1 OF 1	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	0830	0920
NORTH / EAST	DATE	DATE	DATE
DATUM ft. msl / ELEVATION 734.51	CASING DEPTH	10-21-94	10-21-94

DRILL RIG | SURFACE CONDITIONS

ANGLE Vertical | BEARING ------

SAMPLE HAMMER TORQUE | FT.-LBS

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	8, 13, 13, 17, 15"		1 Brown CLAY (CL), moist, plastic, 20% silt and limestone fragments (FILL).	SS						
2–4	22, 22, 19, 12, 10"		2 Pale brown SILT (ML), dry, non-plastic, 50% clay, 50% limestone fragments (FILL).	SS						
4–6	26, 20, 19, 20, 8"		3 Pale yellow CLAY (CL), dry, plastic, 20% silt, 50% limestone fragments (FILL).	SS						
6–8	30, 50/3, 2"		4 LIMESTONE (LS) fragments, trace fine sand and silt (FILL).	SS						
8–10	33, 50/4, 4"		5 LIMESTONE (LS) fragments (FILL).	SS						
10–12	26, 20, 16, 20, 6"		6 LIMESTONE (LS) fragments, some fossiliferous fragments (FILL).	SS						
12–14	47, 13, 10, 10, 8"		7 Light yellowish brown SAND (SW), saturated, fine- to medium-grained, 10% silt.	SS						
14–15			END OF BORING AT 14.0 FEET.							

DRILLING CONTR

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DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger		BORING NO. B-62
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler		SHEET 1 OF 1
			DRILLING
			START / FINISH
	WATER LEVEL		TIME / TIME
	TIME		1347 / 1458
NORTH / EAST	DATE		DATE / DATE
DATUM ft. msl / ELEVATION 731.27	CASING DEPTH		10-20-94 / 10-20-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING -------			
SAMPLE HAMMER TORQUE / FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER	DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	7, 9, 6, 5 (18")		1	Dark brown CLAY (CL), moist, 30% clay, 10% fine gravel (0 to 0.2"). Yellow brown POORLY GRADED GRAVEL (GP), damp, 20% silt, 20% sand. Pale yellow POORLY GRADED SAND (SP), dry, fine- to medium-grained.	SS						
2–4	6, 16, 15, 17 (12")		2	Yellowish gray WELL GRADED SAND (SW), dry, 40% angular gravel, 10% silt.	SS						
4–6	14, 18, 16, 15 (6")		3	Yellowish gray WELL GRADED SAND (SW), dry, 30% coarse (<1") gravel, 15% silt.	SS						
6–8	19, 20, 20, 22 (0")		4	No Recovery	SS						
8–10	15, 7, 7, 8 (8")		5	Yellowish brown CLAY (CL), damp, 40% sand, 5% silt, 10% fine gravel.	SS						
10–12	14, 23, 36 (12")		6	WELL GRADED GRAVEL (GW), dry, angular, 20% sand, 5% silt, Black CLAY (CL), moist, 20% sand.	SS						
12–14	6, 5, 8, 12 (10")		7	Olive, black mottled POORLY GRADED SAND (SP), saturated, 30% gravel, 5% silt.	SS						
14–15				END OF BORING AT 14.0 FEET.							

DRILLING CONTR. FS

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SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-63	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 1 OF 2	
		DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	1545	0952
NORTH EAST	DATE	DATE	DATE
DATUM ft. msl ELEVATION 733.86	CASING DEPTH	10-18-94	10-19-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical BEARING ------			
SAMPLE HAMMER TORQUE FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER	DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0	10 15 18 28 12"		1	Organic SILT (ML), dry, leaves, roots, etc. Dark yellow CLAY (CL), dry, 30% silt.	SS						
2	18 12 14 17 14"		2	Pale yellow SILT (ML), dry, non-plastic.	SS						
4	9 9 10 20 8"		3	Iron oxide staining.	SS						
6	12 12 19 12 8"		4	Pale yellow SILT (ML), dry, non-plastic, trace fine sand.	SS						
8	25 25 30/2 10"		5	Gray limestone GRAVEL (GW), horizontal partings between 1/4 inch gravel.	SS						
10	8 10 12 18 4"		6	Yellow brown SILT (ML), dry. Limestone GRAVEL (GW), dry.	SS						
12	5 12 20 23 2"		7	Limestone GRAVEL (GW), dry.	SS						
14	4 18 19			Light greenish gray WELL GRADED SAND (SW), damp, 20% fine- to medium gravel.							
15											

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DRILLING CONTR. FS

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SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-63	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 2 OF 2	
		DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	1545	0952
NORTH / EAST	DATE	DATE	DATE
DATUM ft. msl / ELEVATION 733.86	CASING DEPTH	10-18-94	10-19-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING ------			
SAMPLE HAMMER TORQUE FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
15	20 4"		8	SS						
16–18 (17)	6 10 13 14 4"		9 Olive SILT (ML), moist, odor, non-plastic, 2% rounded gravel.	SS						
18–20 (19)	6 8 14 20 6"		10 Greenish gray SILT (ML), moist, 20% clay, 10% sand, 5% rounded gravel.	SS						
20–22 (21)	5 18 20 26 8"		11 Olive grading to black WELL GRADED SAND (SW), moist to wet, 20% silt and 30% gravel.	SS						
22–24 (23)	9 8 9 16 10"		12 Free product; black water below product.	SS						
24			END OF BORING AT 24.0 FEET.							
25										
26										
27										
28										
29										
30										

DRILLING CONTR FS

LOGGED BY RUST E&I CHK'D BY

DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION	Skinner Landfill - West, Chester, Ohio
DRILLING METHOD:	Hollow-Stem Auger
SAMPLING METHOD:	2.0 ft. Split-Spoon Sampler
BORING NO.	B-64
SHEET	1 OF 3
NORTH	
EAST	
DATUM	ft. msl
ELEVATION	
DRILL RIG	
ANGLE	Vertical
BEARING	-------
SAMPLE HAMMER TORQUE	FT.-LBS
SURFACE CONDITIONS	

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING	START	FINISH
TIME	0925	1435
DATE	10-20-94	10-20-94

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	11, 15, 50/2, 6"		1 Brown CLAY (CL), moist, plastic, 20% silt, rock fragments (FILL).	SS						
2–4	9, 12, 14, 12, 10"		2 Brown CLAY (CL), damp, plastic, 15% silt, rock fragments (FILL).	SS						
4–6	13, 11, 12, 14, 6"		3 Brown CLAY (CL), damp, plastic, 15% silt, rock fragments (FILL).	SS						
6–8	10, 13, 36, 41, 12"		4 Brown CLAY (CL), damp, plastic, 15% silt, rock fragments (FILL).	SS						
8–10	15, 33, 30, 29, 15"		5 Paie yellow CLAY (CL), dry, non-plastic, 25% silt, rock fragments (FILL).	SS						
10–12	17, 34, 38, 22, 8"		6 Paie yellow CLAY (CL), dry, non-plastic, 25% silt, limestone fragments (FILL).	SS						
12–14	30, 22, 24, 20, 8"		7 Damp, plastic, 30% silt.	SS						
14–15	50/2, 2"									

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DRILLING CONTR

FS

SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-64	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 2 OF 3	
		DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	0925	1435
NORTH / EAST	DATE	DATE	DATE
DATUM ft. msl / ELEVATION	CASING DEPTH	10-20-94	10-20-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING ------			
SAMPLE HAMMER TORQUE FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER	DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
15			8		SS						
16–18	47, 20, 26, 29, 12"		9	Pale yellow SILT (ML), moist, non-plastic, 10% clay, 15% fine sand and limestone fragments (FILL).	SS						
18–20	16, 18, 22, 24, 12"		10	Pale yellow CLAY (CL), moist, plastic, 20% silt with limestone fragments (FILL).	SS						
20–22	16, 17, 26, 32, 4"		11	Brown CLAY (CL), damp, plastic, 15% silt with limestone fragments.	SS						
22–24	16, 19, 26, 19, 15"		12	Gray SAND (SW), dry, non-plastic, fine- to medium-grained, trace limestone gravel.	SS						
24–26	18, 17, 17, 16, 15"		13	Gray SAND (SW), dry, non-plastic, fine- to medium-grained, trace limestone gravel.	SS						
26–28	6, 12, 18, 19, 4"		14	Gray SAND (SW), dry, non-plastic, fine- to medium-grained, 10% silt, 30% fine gravel.	SS						
28–30	4, 8, 26, 32, 8"		15	Gray SAND (SW), dry, non-plastic, fine- to medium-grained, 30% fine gravel.	SS						

Continued Next Page

DRILLING CONTR

FS

CHK'D BY

LOGGED BY RUST E&I

DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION: Skinner Landfill - West, Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger		BORING NO. B-64
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler		SHEET 3 OF 3
	WATER LEVEL		DRILLING START TIME 0925 / FINISH TIME 1435
	TIME		
NORTH / EAST	DATE		START DATE 10-20-94 / FINISH DATE 10-20-94
DATUM ft. msl / ELEVATION	CASING DEPTH		
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING -------			
SAMPLE HAMMER TORQUE FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
30–32	6, 8, 13, 14 (10")		16 — Gray to dark gray SAND (SW), damp, fine- to coarse-grained, 25% silt, 10% fine gravel.	SS						
32–34	6, 18, 26, 32 (12")		17 — Gray SAND (SW), dry, non-plastic, fine- to medium-grained, trace gravel.	SS						
34–36	10, 15, 32, 36 (12")		18 — Gray and pale yellow SAND (SW), damp, fine- to medium-grained, 15% silt and trace fine gravel.	SS						
36–38	8, 18, 36, 42 (8")		19 — Gray SAND (SW), damp, fine- to medium-grained, 20% fine gravel, odor.	SS						
38–40	4, 8, 14, 18 (8")		20 — Gray SAND (SW), moist, fine- to medium-grained, 20% silt, trace gravel, odor.	SS						
40–42	4, 8, 9, 13 (8")		21 — Gray to dark gray SAND (SW), moist, fine- to coarse-grained, 10% silt, trace gravel, odor. Saturated	SS						
42–45			END OF BORING AT 42.0 FEET.							

DRILLING CONTR. FS

CHK'D BY

LOGGED BY RUST E&I

DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	BORING NO. B-65 SHEET 1 OF 2

WATER LEVEL			
TIME			
DATE			
CASING DEPTH			

DRILLING	START	FINISH
TIME	1520	1632
DATE	10-25-94	10-25-94

NORTH EAST

DATUM ft. msl ELEVATION 733.01

DRILL RIG SURFACE CONDITIONS

ANGLE Vertical BEARING ------

SAMPLE HAMMER TORQUE FT.-LBS

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	3, 5, 12, 16, 8"		1 SILT (ML), dry, 20% clay, 5% angular gravel (FILL).	SS						
2–4	12, 32, 33, 36, 10"		2 SILT (ML), dry, 30% subangular gravel, 10% sand (FILL).	SS						
4–6	12, 50/4, 4"		3	SS						
6–8	50/5, 3"		4	SS						
8–10	21, 22, 22, 20		5 SILT (ML), dry, 10% clay, 5% sand, 5% fine, rounded gravel.	SS						
10–12	50/0, 3"		6	SS						
12–14	67, 32, 30, 34, 10"		7 Moist, non-plastic.	SS						
14–15	3, 15, 16		SILT (ML), damp, 20% sand, 5% rounded gravel, 5% clay.							

Continued Next Page

DRILLING CONTR.

FS

CHK'D BY

LOGGED BY RUST E&I

DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West
Chester, Ohio

DRILLING METHOD: Hollow-Stem Auger

SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler

BORING NO. B-65

SHEET 2 OF 2

DRILLING

	START	FINISH
TIME	1520	1632
DATE	10-25-94	10-25-94

WATER LEVEL
TIME
DATE
CASING DEPTH

NORTH　EAST

DATUM ft. msl　ELEVATION 733.01

DRILL RIG　SURFACE CONDITIONS

ANGLE Vertical　BEARING -------

SAMPLE HAMMER TORQUE　FT.-LBS

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
15	19 10"		8	SS						
16	7 8 8 8 15"		POORLY GRADED SAND (SP), moist, fine-grained, interbedded with thin strings of medium to coarse, rounded gravel.							
17			9	SS						
18	19"									
19			10	SS						
			WELL GRADED SAND (SW), moist.							
20	8 10 11 11 12"		Saturated.							
21			11	SS						
22			END OF BORING AT 22.0 FEET.							
23										
24										
25										
26										
27										
28										
29										
30										

DRILLING CONTR　FS

LOGGED BY RUST E&I　CHK'D BY

DATE 5/18/95

SOIL BOREHOLE LOG

SITE NAME AND LOCATION: Skinner Landfill - West, Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-66	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 1 OF 2	
		DRILLING	
		START	FINISH
	WATER LEVEL	TIME	TIME
	TIME	0925	1350
NORTH / EAST	DATE	DATE	DATE
DATUM ft. msl / ELEVATION 732.64	CASING DEPTH	10-25-94	10-25-94
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING ------			
SAMPLE HAMMER TORQUE / FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SAMPLE NUMBER	DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
0–2	7, 12, 10, 22, 12"	1	SILT (ML), dry, 30% gravel, 10% sand.	SS						
2–4	12, 13, 50/4, 8"	2	SILT (ML), dry, 20% fine to medium, subangular gravel, laminae structure, thin.	SS						
4–6	14, 16, 14, 14, 13"	3		SS						
6–8	14, 15, 9, 8, 14"	4	No partings.	SS						
8–10	10, 13, 16, 18, 19"	5	Moist, subrounded gravel.	SS						
10–12	7, 10, 15, 25, 15"	6	SILT (ML), moist, low plasticity, 20% clay, 20% subrounded gravel, 2% sand.	SS						
12–14	8, 15, 20, 24, 13"	7	WELL GRADED SAND (SW), moist, 10% silt, 10% rounded gravel.	SS						
14–15	9, 14, 15		Damp, 10% to 30% silt.							

Continued Next Page

DRILLING CONTR

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DATE 5/18/95 CHK'D BY FS

SOIL BOREHOLE LOG

SITE NAME AND LOCATION Skinner Landfill - West Chester, Ohio	DRILLING METHOD: Hollow-Stem Auger	BORING NO. B-66	
	SAMPLING METHOD: 2.0 ft. Split-Spoon Sampler	SHEET 2 OF 2	
		DRILLING	
	WATER LEVEL	START	FINISH
	TIME	TIME 0925	TIME 1350
NORTH / EAST	DATE	DATE 10-25-94	DATE 10-25-94
DATUM ft. msl / ELEVATION 732.64	CASING DEPTH		
DRILL RIG	SURFACE CONDITIONS		
ANGLE Vertical / BEARING -------			
SAMPLE HAMMER TORQUE FT.-LBS			

DEPTH IN FEET (ELEVATION)	BLOWS/6 IN ON SAMPLER (RECOVERY)	SOIL GRAPH	SAMPLE NUMBER AND DESCRIPTION OF MATERIALS	SAMPLER AND BIT	CASING TYPE	BLOWS/FOOT ON CASING	WATER CONTENT %	LIQUID LIMIT %	PLASTIC LIMIT %	SPECIFIC GRAVITY
15	18 12"		8	SS						
16–18	10 11 17 24 12"		9 WELL GRADED SAND (SW), damp, 5% silt, 5% fine, subrounded gravel.	SS						
18–20	2 50/4 6"		10 Damp, no silt.	SS						
20–22	49 50/2 7"		11	SS						
22–24	25 36 50/4 6"		12 CLAY (CL), moist, 5% silt, 10% fine to coarse, rounded gravel, 2% sand. Sand seam at 22.5 feet with black staining.	SS						
24–26	50/4 3"		13	SS						
26–28	22 30 50/3 10"		14 CLAY (CL), dry, 10% silt, 10% gravel. POORLY GRADED SAND (SP), wet, 20% silt. Very thin stringer of coarse sand at 27.5 feet.	SS						
28–30	18 17 14 12 22"		15 POORLY SORTED SAND (SP), wet to saturated, medium to coarse gravel. END OF BORING AT 30.0 FEET.	SS						

DRILLING CONTR

FS

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DATE 5/18/95

APPENDIX B

Grain Size Distribution Reports

A grain size distribution chart typically quantifies the various particle sizes indicating general depositional trends. The distribution of the percentage of the total sample less than a certain sieve size can be plotted in a cumulative frequency diagram. The equivalent grain sizes are plotted to a logarithmic scale on the abscissa, while the percentage by mass of the total sample passing (finer than) is plotted arithmetically on the ordinate. An example of some characteristic grain size distributions are shown in this appendix. As shown in the figure, a well-graded soil is one which has a good representation of particle sizes over a wide range, and its gradation curve is smooth and generally concave upward. A poorly graded soil would be one where there is either an excess or deficiency of certain sizes or if most of the particles are about the same size. The uniform soil gradation shown is an example of a poorly graded soil. The Skinner soil samples tend to be characterized as well graded sand, silt and clay, with the grain size distribution report being shown in the following pages.

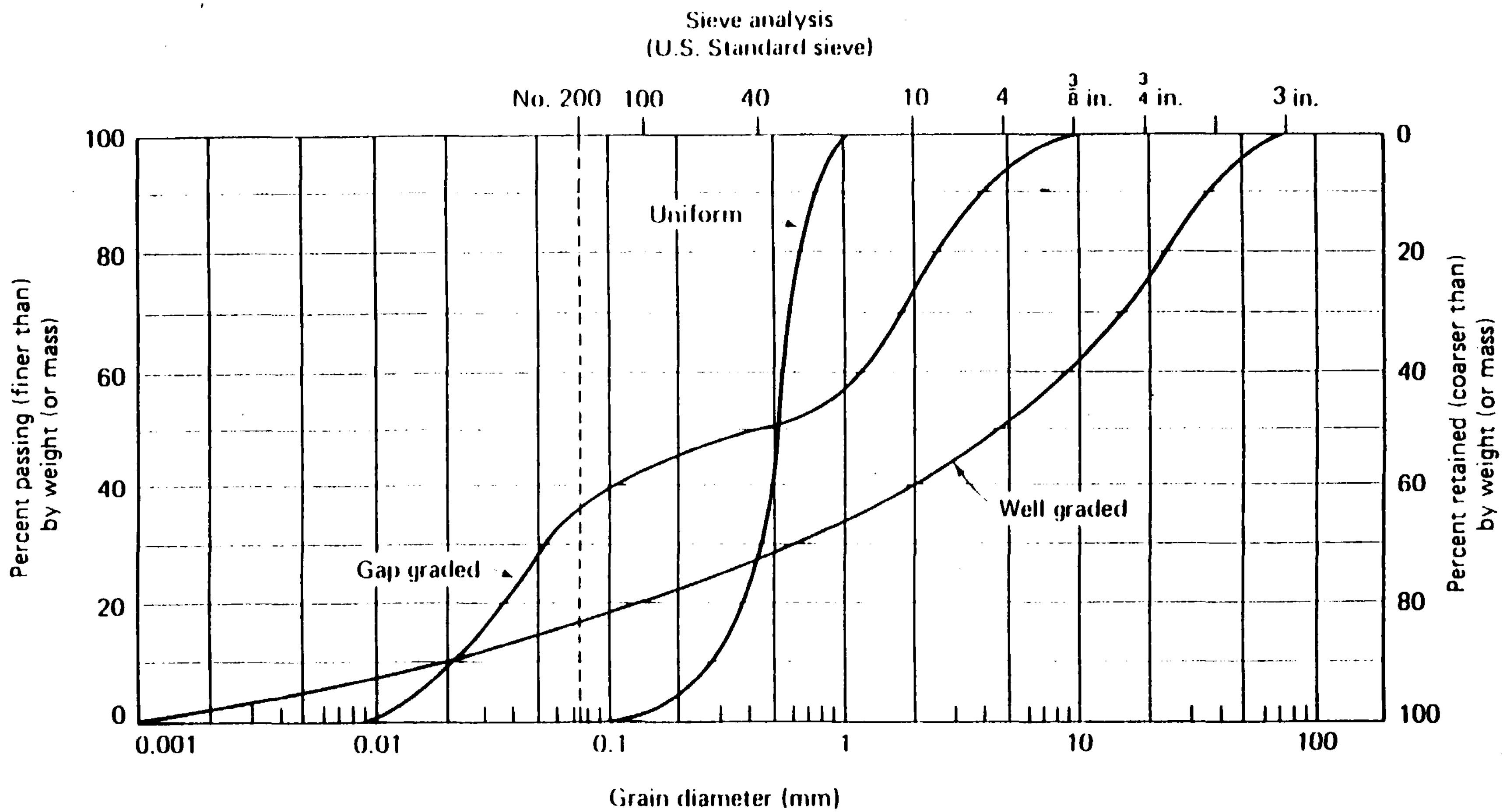
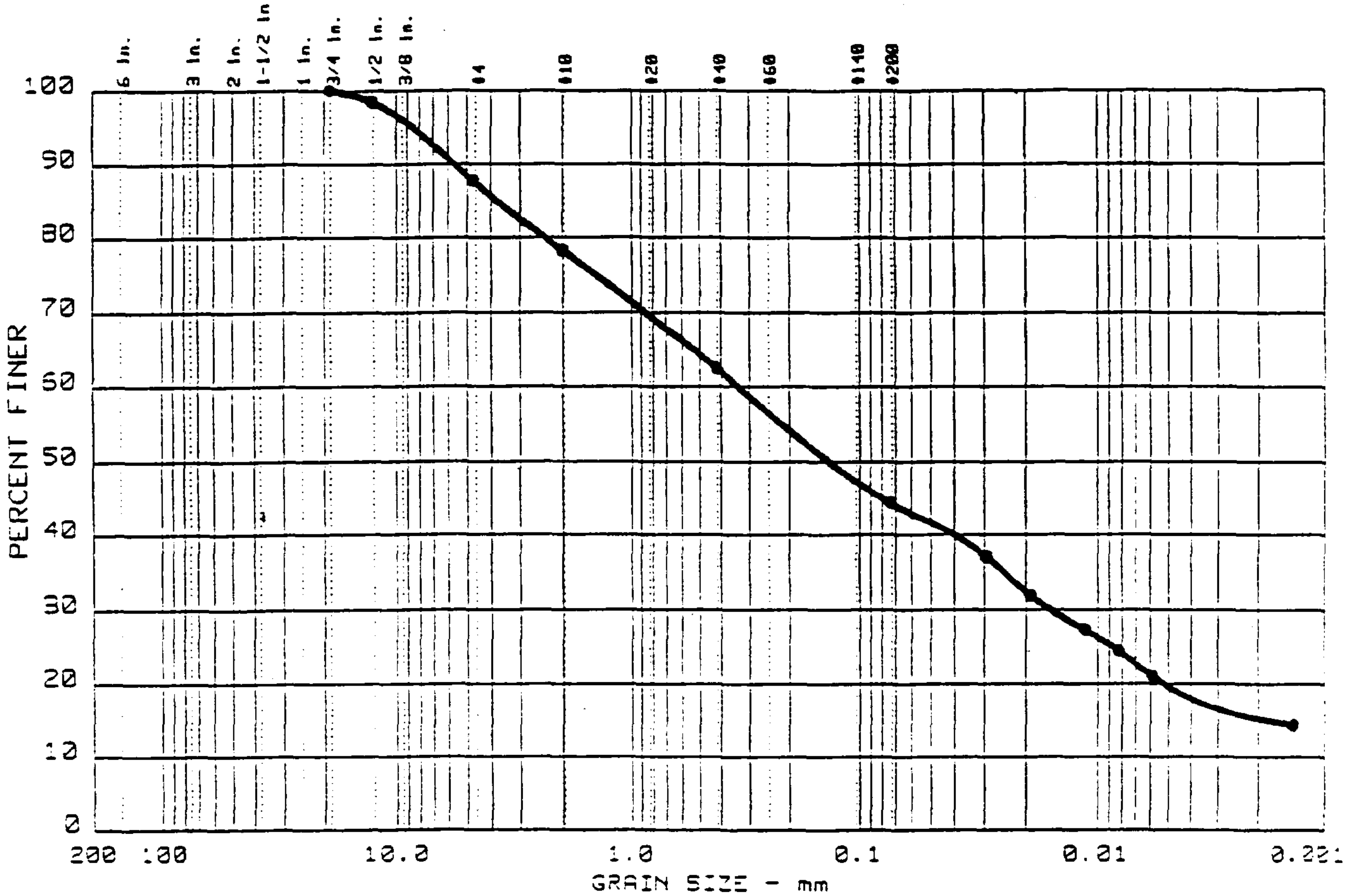


Fig. 2.4 Typical grain size distributions.

[HOLTZ, R.D, GEOTECHNICAL ENGINEERING, ENGLEWOOD CLIFFS, N.J., 1981, p30.]

PARTICLE SIZE DISTRIBUTION - ASTM D422



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	12.3	43.4	29.3	15.0	SC-SM	20.4	26.3

SIEVE inches size	PERCENT FINER ●		
0.75	100.0		
0.5	98.4		

GRAIN SIZE			
D_{60}	0.33		
D_{30}	0.02		
D_{10}			

COEFFICIENTS			
C_c			
C_u			

SIEVE number size	PERCENT FINER ●		
4	87.7		
10	78.2		
40	62.5		
200	44.3		

Sample information:

● B-59 @ 14'-16'
BROWN AND GRAY
SILTY, CLAYEY SAND

Remarks:
NMC 09.5%

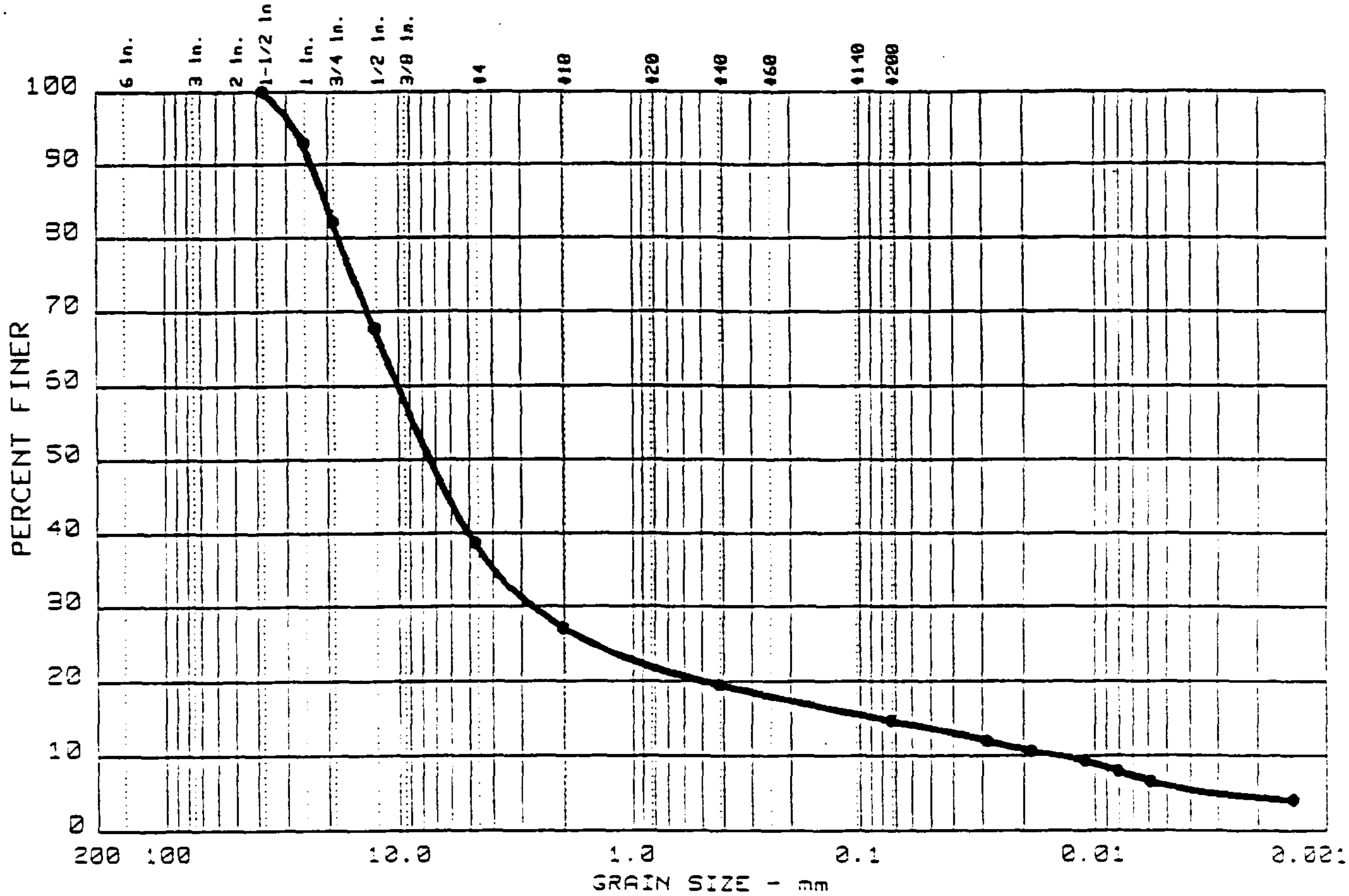
RAN BY: KMP
GR16-02

RUST ENVIRONMENT & INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 12.27.94 Lab. No. ____

PARTICLE SIZE DISTRIBUTION - ASTM D422



	% -3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	61.3	24.0	10.3	4.4	GC-GM	23.0	25.3

SIEVE inches size	PERCENT FINER ●		
1.5	100.0		
1	92.8		
0.75	82.0		
0.5	67.6		

	GRAIN SIZE		
D_{60}	10.10		
D_{30}	2.72		
D_{10}	0.01		

	COEFFICIENTS		
C_c	55.59		
C_u	767.4		

SIEVE number size	PERCENT FINER ●		
4	38.7		
10	27.0		
40	19.5		
200	14.7		

Sample information:

● B-61 @ 10'-12'
BROWN SILTY, CLAYEY
GRAVEL WITH SAND

Remarks:

NMC 02.8%

RAN BY: KMP

GR16-03

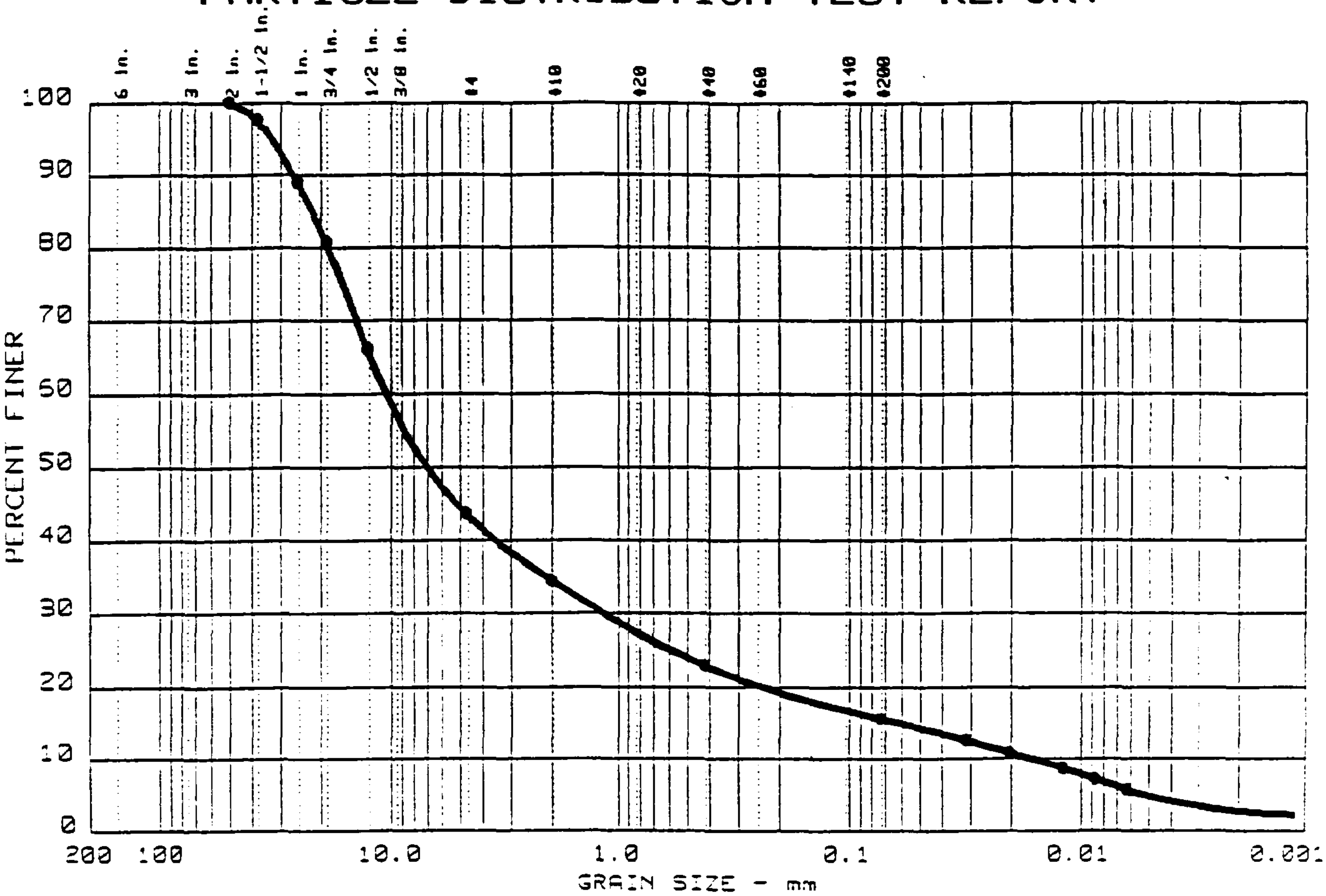
RUST ENVIRONMENT & INFRASTRUCTURE

Project No.: 72680.300

Project: SKINNER LANDFILL

Date: 12.07.94 Lab. No.

PARTICLE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	56.3	23.0	12.9	2.8	GC-GM	22.2	04.9

SIEVE inches size	PERCENT FINER ●		
2	100.0		
1.5	97.6		
1	88.8		
0.75	80.7		
0.5	66.0		
	GRAIN SIZE		
D_{60}	10.47		
D_{30}	1.17		
D_{10}	0.01		
	COEFFICIENTS		
C_c	8.13		
C_u	645.7		

SIEVE number size	PERCENT FINER ●		
4	43.7		
10	34.4		
40	22.9		
200	15.7		

Sample information:
● B-62 @ 14'- 16'
SILTY CLAYEY GRAVEL
WITH SAND

Remarks:
NMC 04.2%

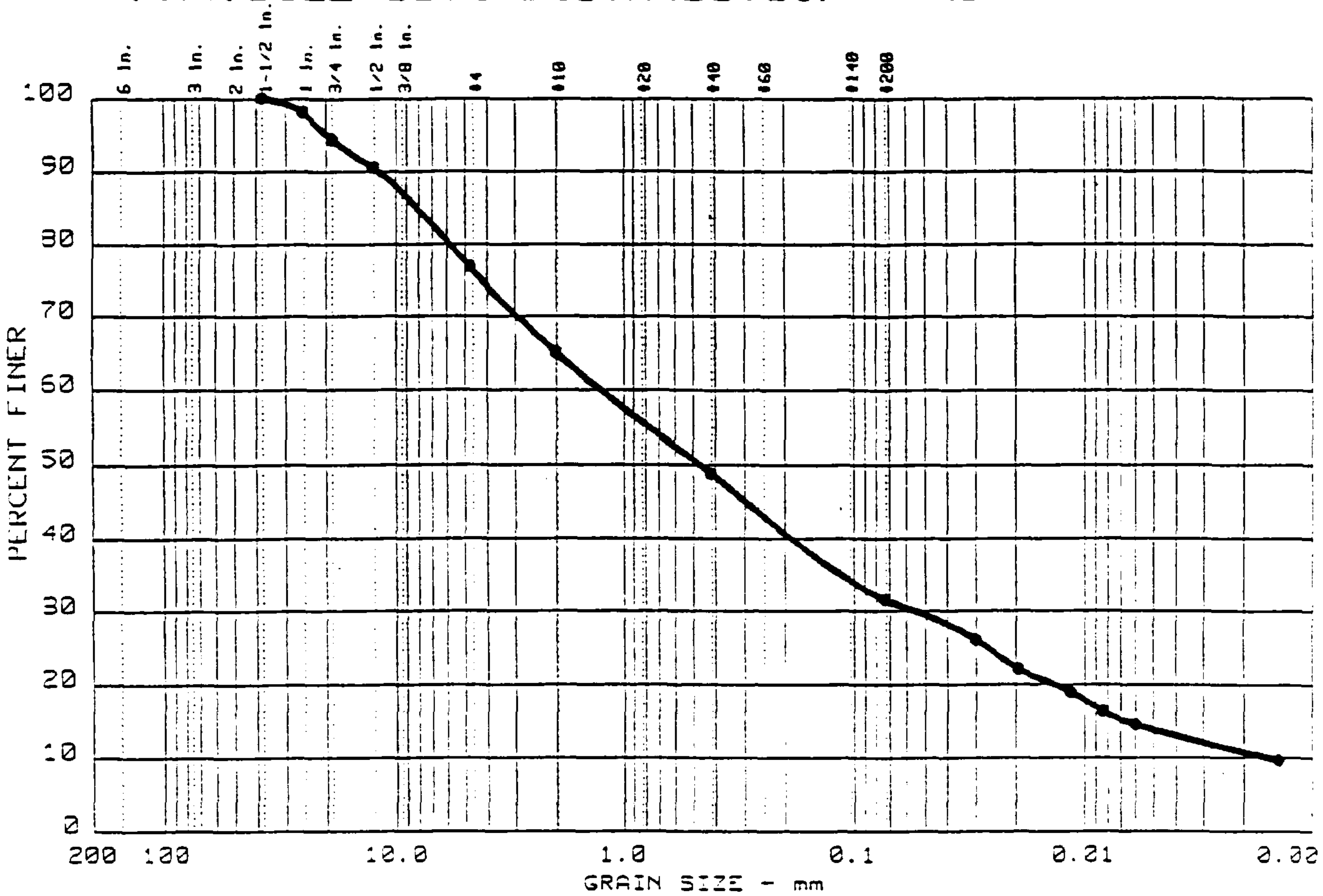
RAN BY: SB
GR7-09

RUST
ENVIRONMENT &
INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 11.15.94 Lab. No.

PARTICLE SIZE DISTRIBUTION - ASTM D422



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	23.1	45.3	20.8	10.8	SC-SM	19.2	04.9

SIEVE inches size	PERCENT FINER ●		
1.5	100.0		
1	98.0		
0.75	94.3		
0.5	90.5		
	GRAIN SIZE		
D_{60}	1.25		
D_{30}	0.06		
D_{10}	0.00		
	COEFFICIENTS		
C_c	1.64		
C_u	841.4		

SIEVE number size	PERCENT FINER ●		
4	76.9		
10	65.0		
40	48.8		
200	31.6		

Sample information:

● B-63 @ 16'-20'
BROWN SILTY, CLAYEY
SAND WITH GRAVEL

Remarks:
NMC 08.1%

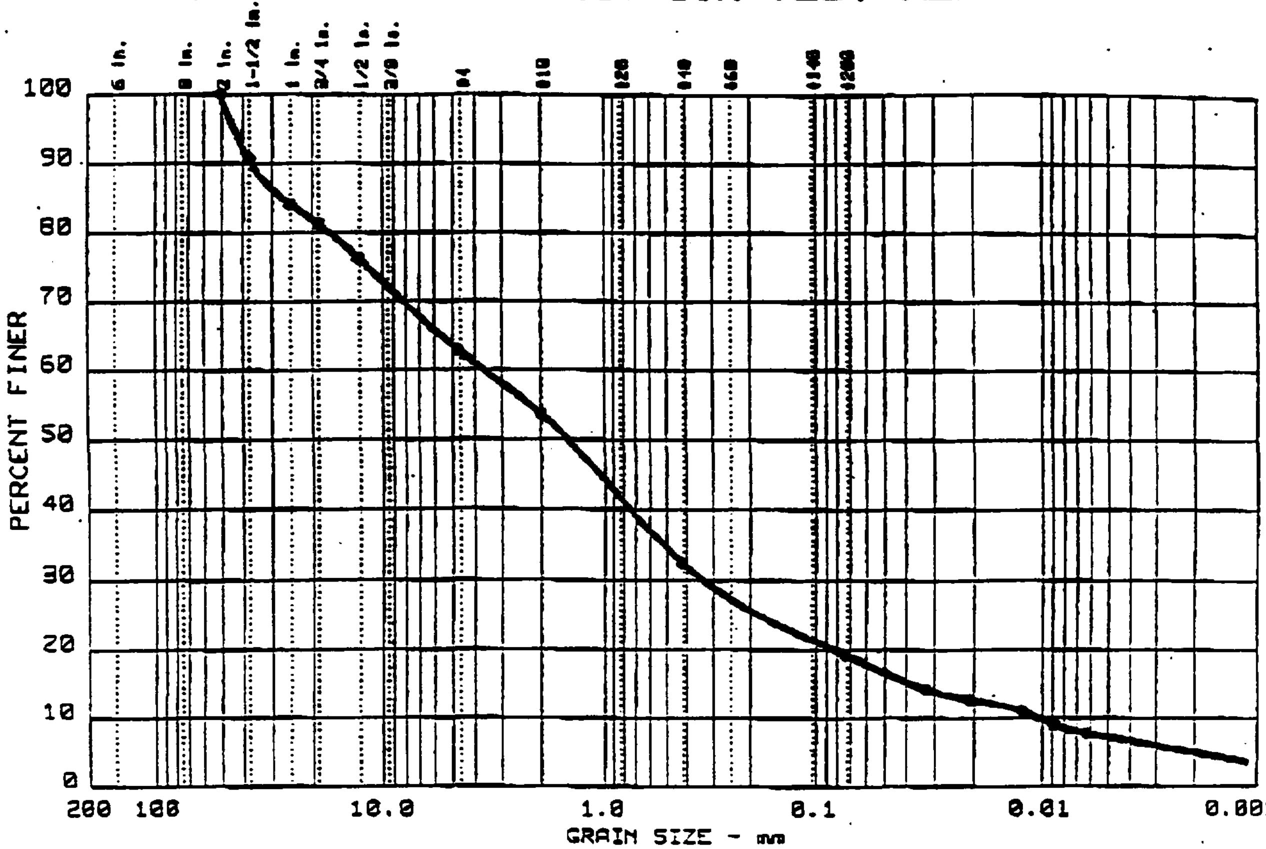
RAN BY: KMP
GR16-04

RUST
ENVIRONMENT &
INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 12.09.94 Lab. No. ____

PARTICLE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	37.3	43.5	14.4	4.8	SM	17.4	01.3

SIEVE inches size	PERCENT FINER ●		
2	100.0		
1.5	90.6		
1	84.1		
0.75	81.2		
0.5	76.3		
	GRAIN SIZE		
D_{60}	3.67		
D_{30}	0.33		
D_{10}	0.01		
	COEFFICIENTS		
C_c	2.82		
C_u	346.7		

SIEVE number size	PERCENT FINER ●		
4	62.7		
10	53.7		
40	32.4		
200	19.2		

Sample information:
● B-64 @ 18'- 22'
SILTY SAND WITH GRAVEL

Remarks:
NMC 05.8%

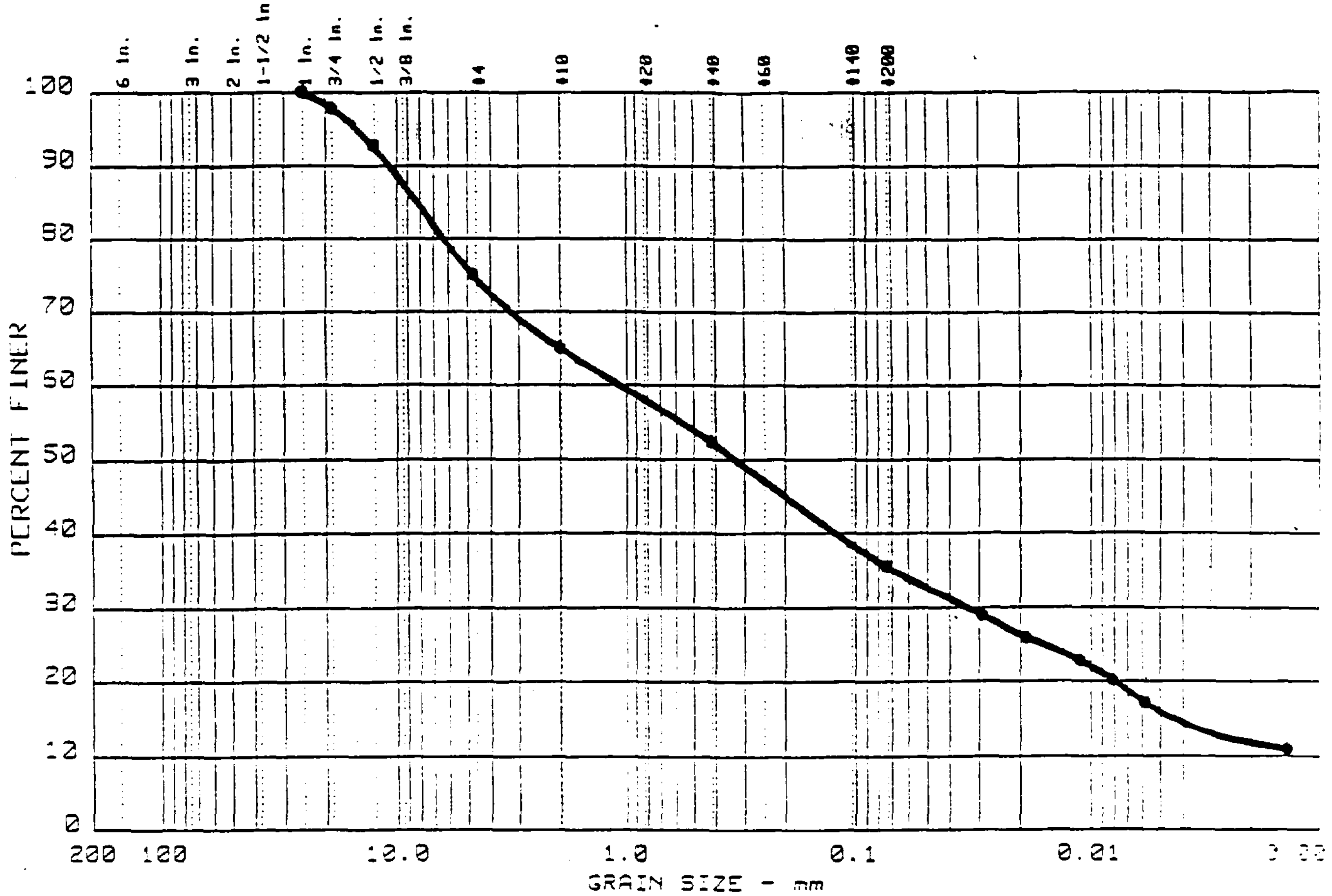
RAN BY: SB
GR7-10

RUST ENVIRONMENT & INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 11.15.94 Lab. No. ——

PARTICLE SIZE DISTRIBUTION - ASTM D422



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	24.9	39.6	23.7	11.8	SC-SM	22.0	[illegible]

SIEVE inches size	PERCENT FINER ●		
1	100.0		
0.75	97.8		
0.5	92.8		
	GRAIN SIZE		
D_{60}	1.08		
D_{30}	0.03		
D_{10}			
	COEFFICIENTS		
C_c	0.6		
C_u	72c		

SIEVE number size	PERCENT FINER ●		
4	75.1		
10	65.0		
40	52.3		
200	35.5		

Sample information:

● B-65 @ 18'-22'
BROWN SILTY, CLAYEY SAND WITH GRAVEL

Remarks:
NMC 07.2%

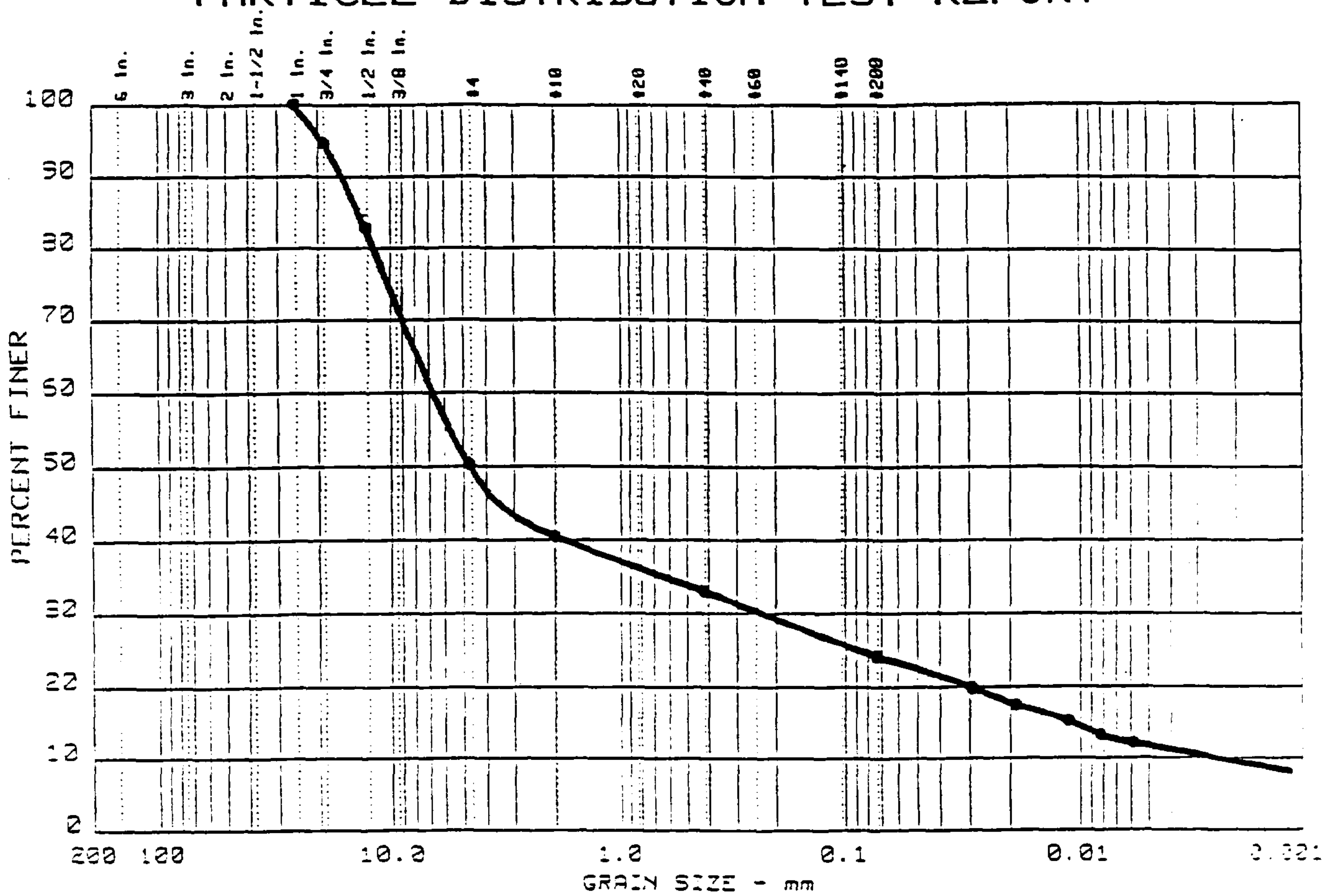
RAN BY: KMF
GR16-05

RUST ENVIRONMENT & INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 12.08.94 Lab. No. ____

PARTICLE DISTRIBUTION TEST REPORT



	% +3"	% GRAVEL	% SAND	% SILT	% CLAY	USCS	LL	PI
●	0.0	49.7	26.1	14.7	9.5	GC	22.5	[illegible]

SIEVE inches size	PERCENT FINER ●		
1	100.0		
0.75	94.7		
0.5	82.6		

	GRAIN SIZE		
D_{60}	6.71		
D_{30}	0.23		
D_{10}	0.00		

	COEFFICIENTS		
C_c	3.20		
C_u	2660.		

SIEVE number size	PERCENT FINER ●		
4	50.3		
10	40.4		
40	33.0		
200	24.1		

Sample information:

● B-66 @ 16'- 18'
CLAYEY GRAVEL WITH SAND

Remarks:
NMC 03.9%

RAN BY: KMK
GR7-20

RUST
ENVIRONMENT &
INFRASTRUCTURE

Project No.: 72680.300
Project: SKINNER LANDFILL

Date: 11.17.94 Lab. No.

APPENDIX C

Coefficient of Uniformity and Curvature Formulas

1) The coefficient of uniformity (C_u) is a crude shape parameter, and is defined as:

$$C_u = \frac{D_{60}}{D_{10}}$$

where D_{60} = grain diameter (mm) corresponding to 60 % passing, and
D_{10} = grain diameter (mm) corresponding to 10 % passing, by mass.

2) Another shape parameter that is often used for soil classification is the coefficient of curvature defined as:

$$C_z = \frac{(D_{30})^2}{(D_{10})(D_{60})}$$

where D_{30} = grain diameter (mm) corresponding to 30% passing,
D_{60} = grain diameter (mm) corresponding to 60 % passing, and
D_{10} = grain diameter (mm) corresponding to 10 % passing, by mass.

APPENDIX D

USDA Triangle Coordinate Soil Classification Charts

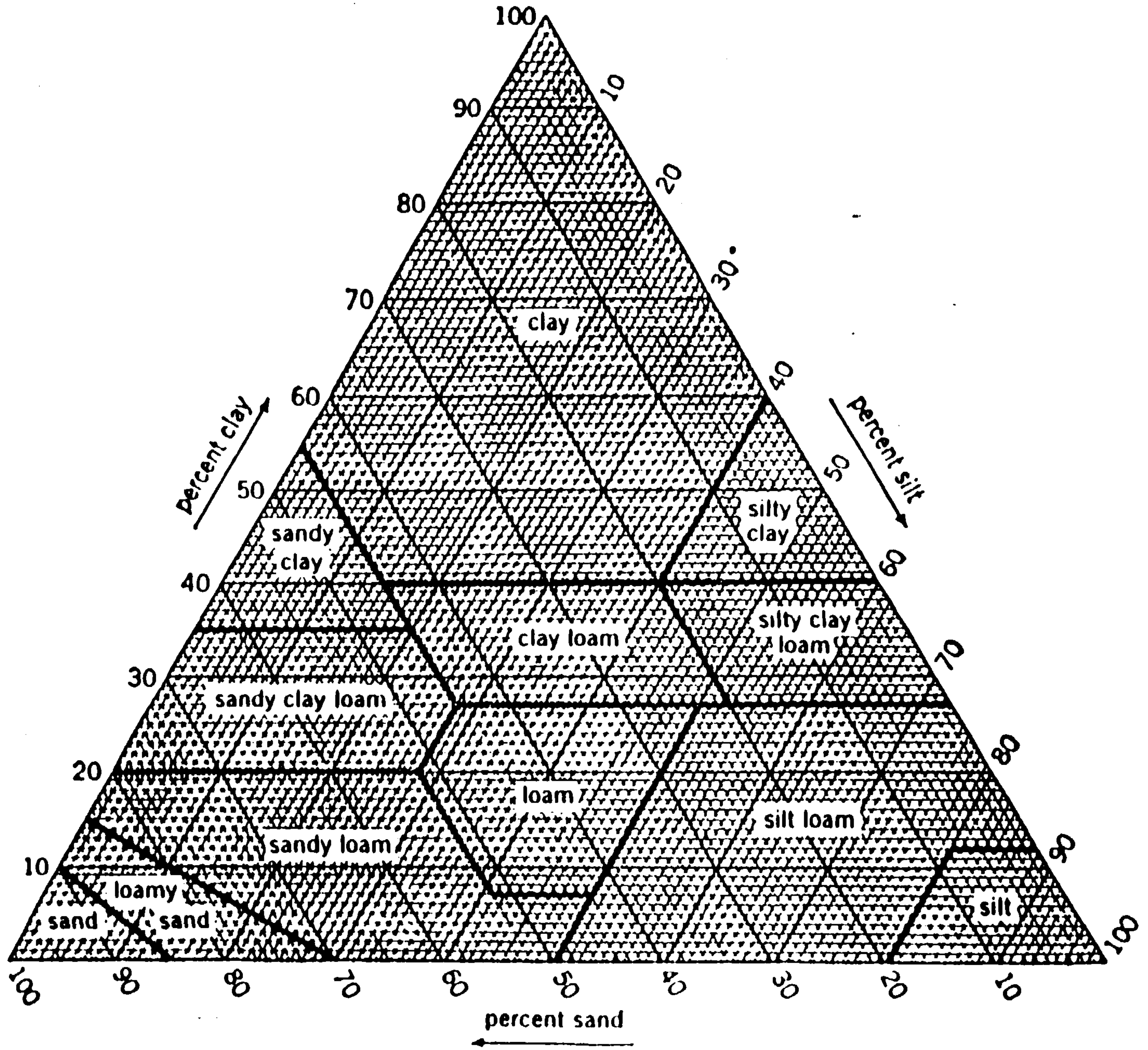


FIGURE 38.—Chart showing the percentages of clay (below 0.002 mm.), silt (0.002 to 0.05 mm.), and sand (0.05 to 2.0 mm.) in the basic soil textural classes.

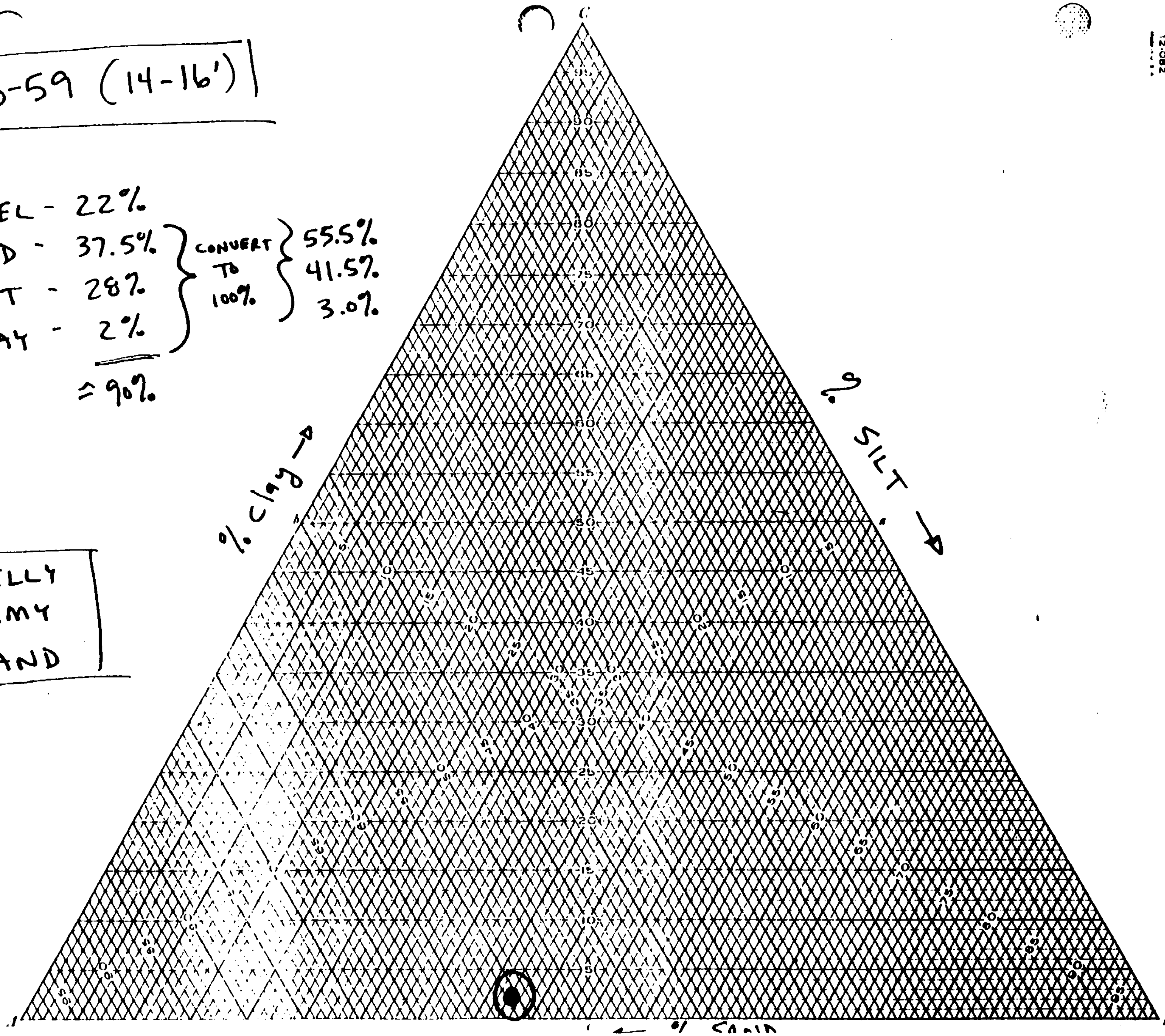
B-59 (14-16')

GRAVEL - 22%
SAND - 37.5%
SILT - 28%
CLAY - 2%

≈ 90%

$\left.\begin{array}{l}\text{SAND} - 37.5\% \\ \text{SILT} - 28\% \\ \text{CLAY} - 2\%\end{array}\right\}$ CONVERT TO 100% $\left\{\begin{array}{l}55.5\% \\ 41.5\% \\ 3.0\%\end{array}\right.$

GRAVELLY LOAMY SAND



Triangular Coordinate

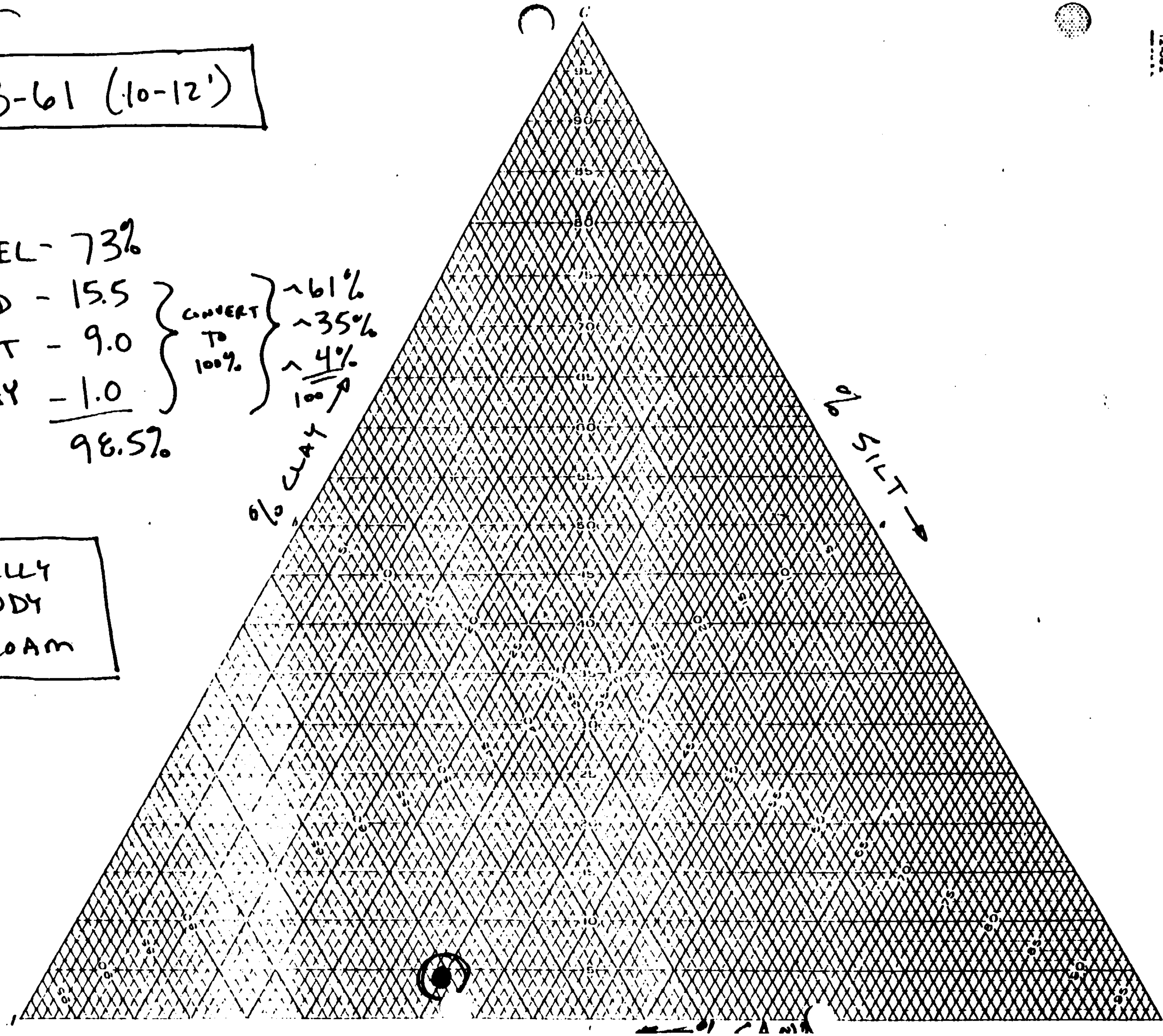
B-61 (10-12')

GRAVEL - 73%
SAND - 15.5
SILT - 9.0
CLAY - 1.0
98.5%

CONVERT TO 100%

~61%
~35%
~4%
100

GRAVELLY SANDY LOAM



B-62 (14-16')

GRAVEL - 65.5
SAND - 21.5
SILT - 12.0
CLAY - 1.0

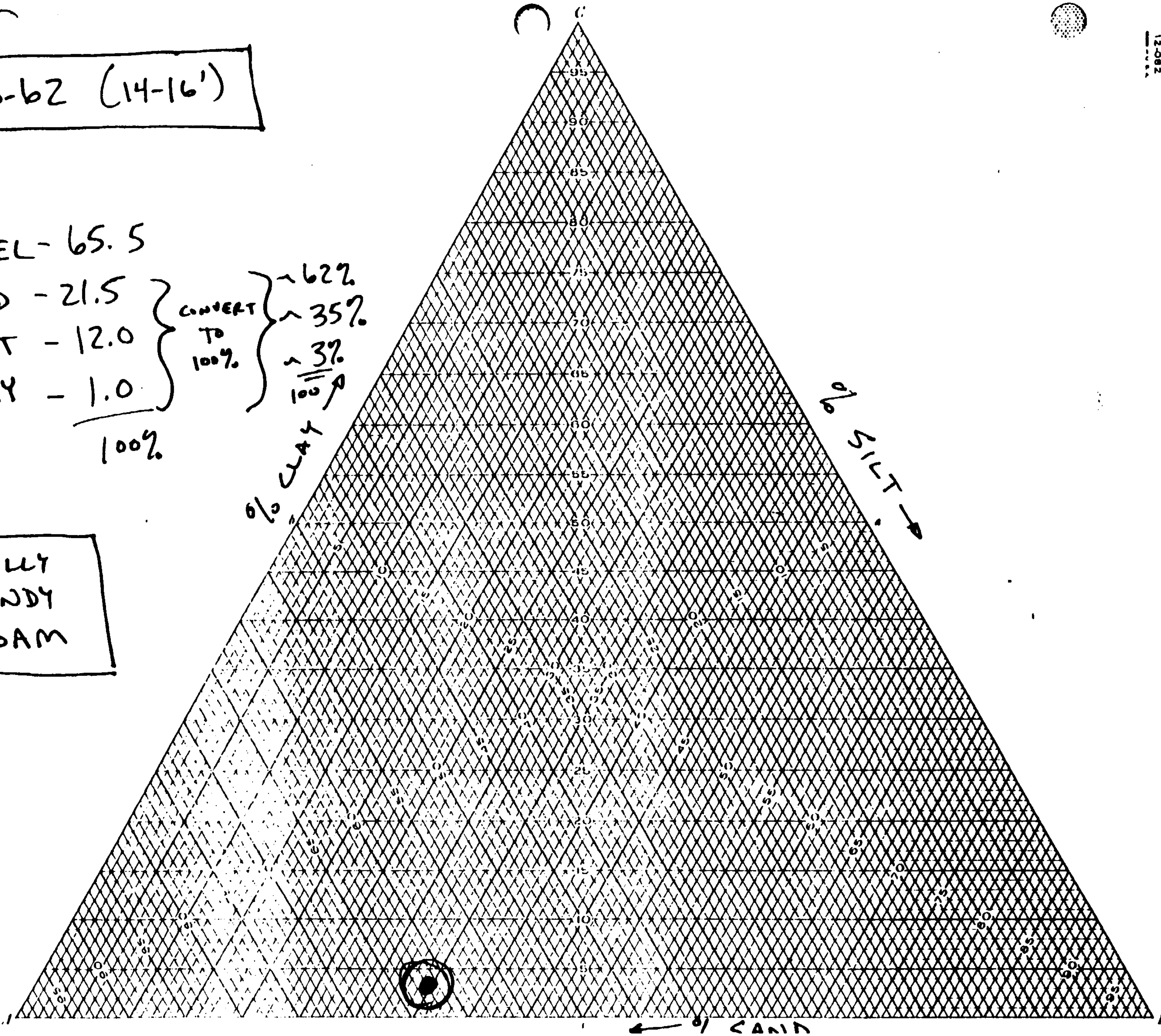
100%

CONVERT TO 100%

~62%
~35%
~3%

100

GRAVELLY SANDY LOAM



Triangular Coordinate

12-082

Triangular Coordinate

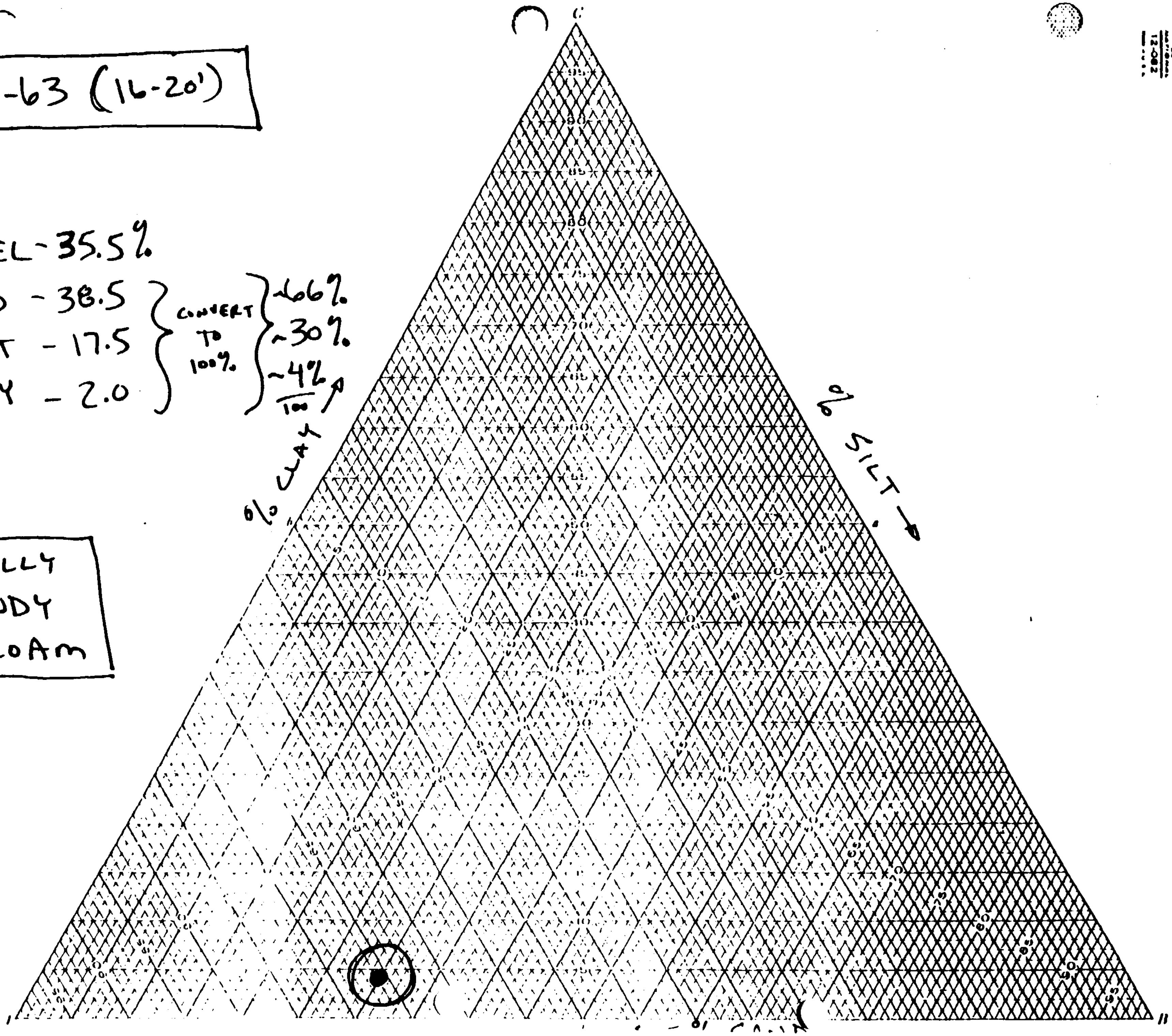
B-63 (16-20')

GRAVEL - 35.5%

SAND - 38.5
SILT - 17.5
CLAY - 2.0

CONVERT TO 100%

~66%
~30%
~4%
100



GRAVELLY SANDY LOAM

B-65 (18-22')

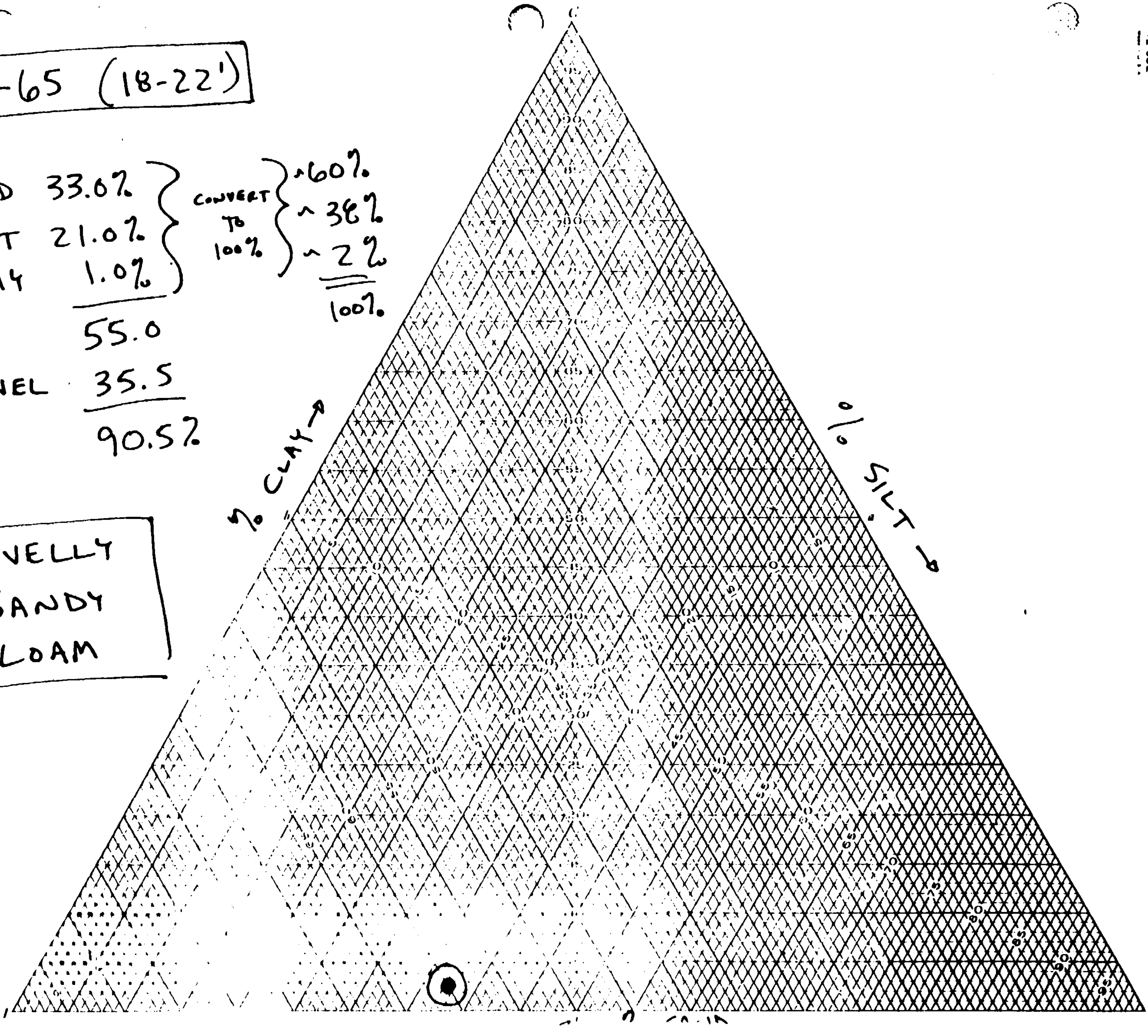
SAND 33.0% ~60%
SILT 21.0% CONVERT TO 100% ~38%
CLAY 1.0% ~2%

55.0 100%

GRAVEL 35.5

90.5%

GRAVELLY SANDY LOAM



B-66 (16-18')

GRAVEL - 59.5%

SAND - 19.5

SILT - 13.5

CLAY - 2.0

CONVERT TO 100%

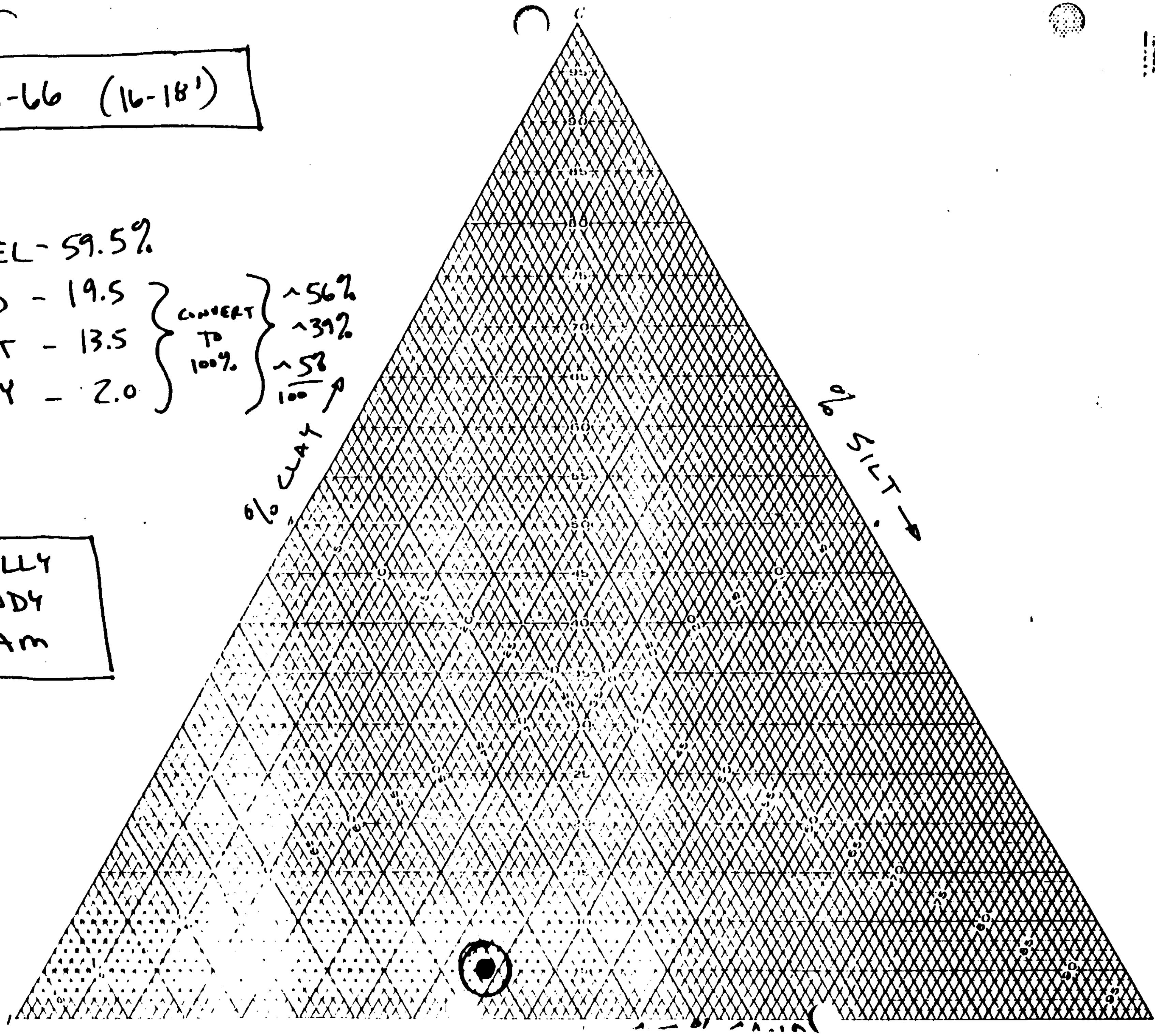
~56%

~39%

~5

100

GRAVELLY SANDY LOAM



Triangular Coordinate

APPENDIX E

Casagrande's Plasticity Chart

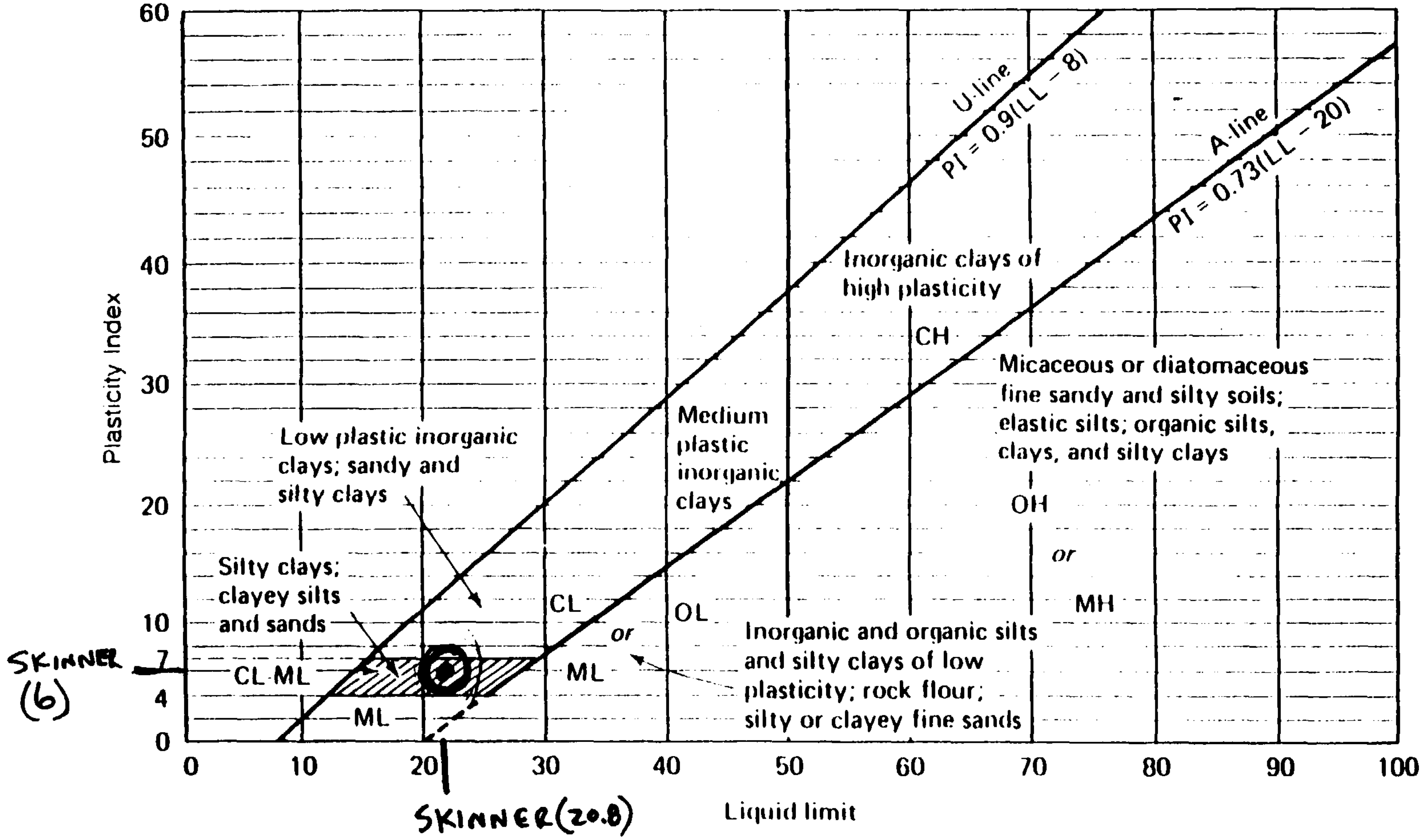
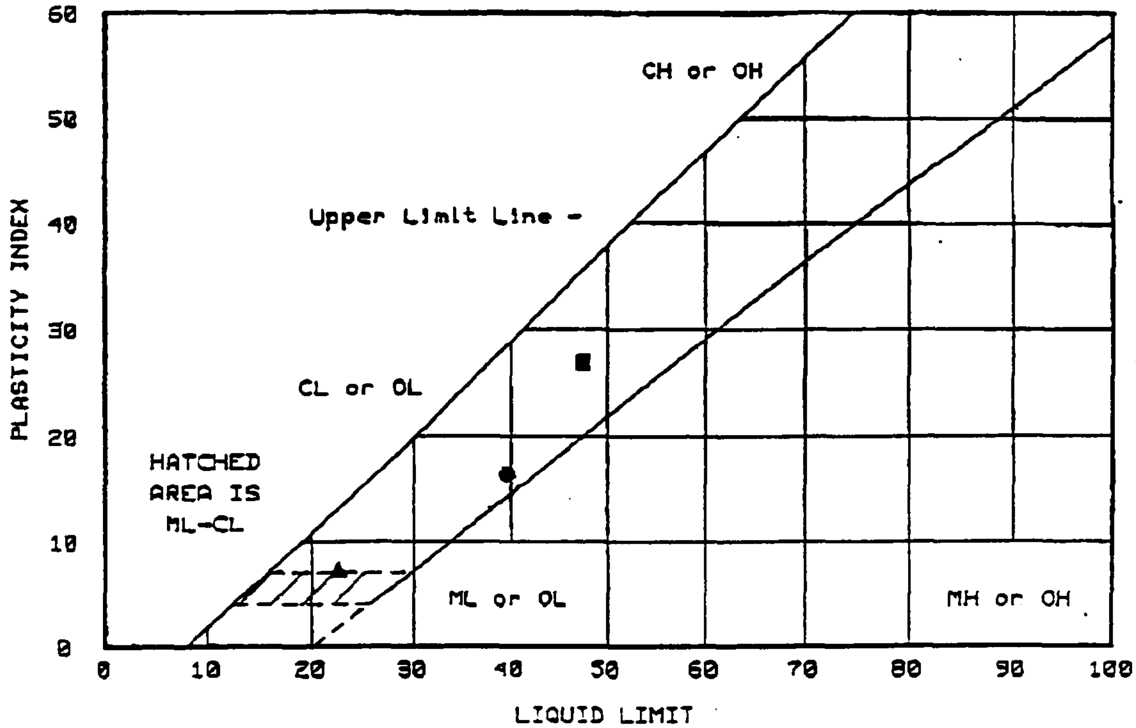


Fig. 3.2 Casagrande's plasticity chart, showing several representative soil types (developed from Casagrande, 1948, and Howard, 1977).

SKINNER – LL = 20.8
PI = 6.0

HOLTZ, R.D., 1981, AN INTRODUCTION TO GEOTECHNICAL ENGINEERING, p53

LIQUID AND PLASTIC LIMITS TEST REPORT



Location + Description	LL	PL	PI	-200	ASTM D 2487-90
● B-64 @ 0'- 6' LEAN CLAY WITH SAND	39.6	23.2	16.4	81.1	CL, Lean clay with sand
▲ B-66 @ 16'- 18' CLAYEY GRAVEL WITH SAND	22.5	15.2	7.3	24.1	GC, Clayey gravel with sand
■ TP-8 @ 0'- 4' LEAN CLAY	47.5	20.7	26.8	85.3	CL, Lean clay

Project No.: 72580.300
Project: SKINNER LANDFILL

Client: SKINNER LANDFILL
Location:

Date: 11.17.94

LIQUID AND PLASTIC LIMITS TEST REPORT

RUST ENVIRONMENT & INFRASTRUCTURE

Remarks:

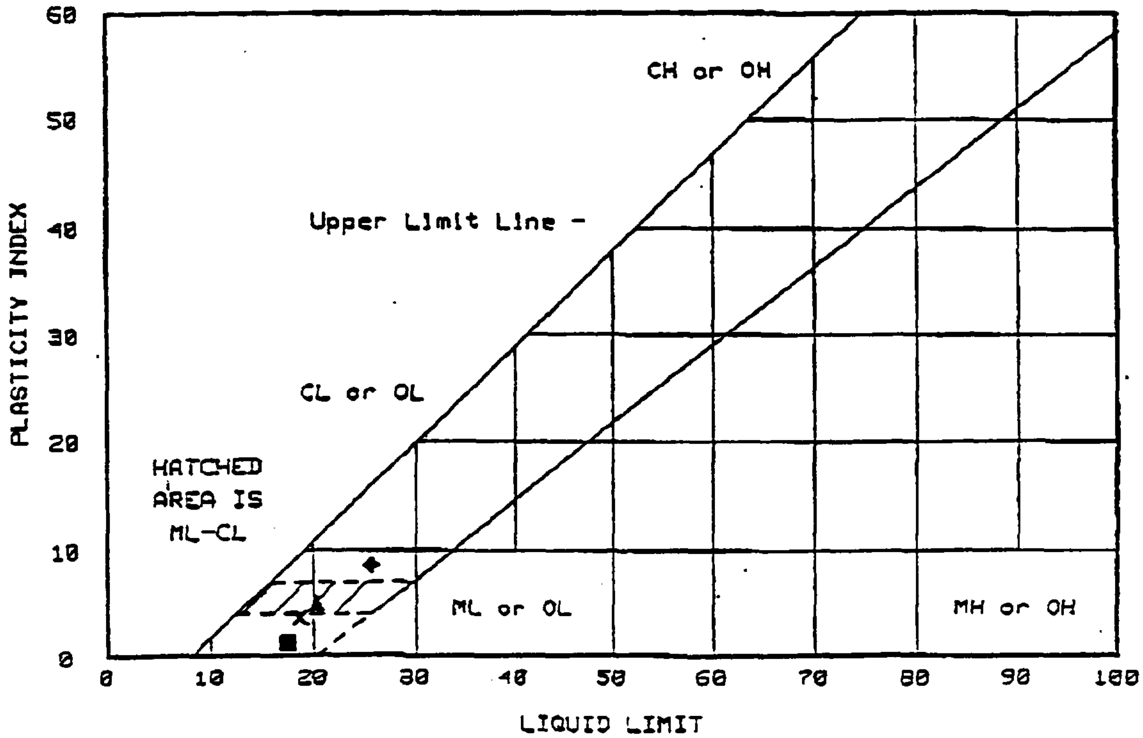
B-64 @ 0'- 6'

B-66 @ 16'- 18'

TP-8 @ 0'- 4'

Lab. No. ______

LIQUID AND PLASTIC LIMITS TEST REPORT



	Location + Description	LL	PL	PI	-200	ASTM D 2487-90
●	B-62 @ 4'- 8' SILTY SAND WITH GRAVEL	NV	NP		15.7	SM, Silty sand with gravel
▲	B-62 @ 14'- 16' SILTY CLAYEY GRAVEL WITH SAND	20.2	15.3	4.9	15.7	GC-GM, Silty clayey gravel with sand
■	B-64 @ 18'- 22' SILTY SAND WITH GRAVEL	17.4	16.1	1.3	19.2	SM, Silty sand with gravel
◆	B-66 @ 4'- 7' CLAYEY GRAVEL WITH SAND	25.6	17.0	8.6	22.8	GC, Clayey gravel with sand
X	GW-51 @ 18'- 22' SILTY GRAVEL WITH SAND	18.6	14.9	3.7	14.6	GM, Silty gravel with sand

NV - Non-Viscous NP - Non-Plastic

Project No.: 72680.300
Project: SKINNER LANDFILL

Client: SKINNER LANDFILL
Location:

Date: 11.15.94

LIQUID AND PLASTIC LIMITS TEST REPORT

RUST ENVIRONMENT & INFRASTRUCTURE

Remarks:

B-62 @ 4'- 8'

B-62 @ 14'- 16'

B-64 @ 18'- 22'

B-66 @ 4'- 7'

GW-51 @ 18'- 22'

Lab. No. ______

APPENDIX F

Gas Permeability Calculations

RUST ENVIRONMENT & INFRASTRUCTURE

CALCULATION SHEET

PROJECT NO. ____

CLIENT ____ SUBJECT Estimate of gas permeability

PROJECT Skinner Landfill

Prepared By MG Date 4-12-95

Reviewed By ____ Date ____

Approved By ____ Date ____

$K_{water} = 1 \times 10^{-1}$ Darcy $= 1 \times 10^{-4}$ cm/sec $= \underline{0.283}$ ft/day

$$K_g = K_w \frac{\mu_w}{\mu_g} * \frac{\rho_g}{\rho_w}$$

ρ_g (20°C, 1 Atm; 760 mm Hg) = 1.2364 gr/l

ρ_w = 1000 gr/l

$\mu_w = 2 \times 10^{-5}$ lb sec/ft2

$\mu_g = 4 \times 10^{-7}$ ″

$$K_g = K_w * \frac{2 \times 10^{-5}}{4 \times 10^{-7}} * \frac{1.2364}{1000} = 6.2 * 10^{-2} * K_w$$

$K_w = 0.283$ ft/day

$K_g = 6.2 \times 10^{-2} * 0.283$ ft/day $= 1.75 \times 10^{-2}$ ft/day

	K_w	K_g
Zone 1	0.283 ft/day	1.75×10^{-2} ft/day
Zone 2	0.283×10^{-2} ft/day	1.75×10^{-4} ft/day
Zone	0	0

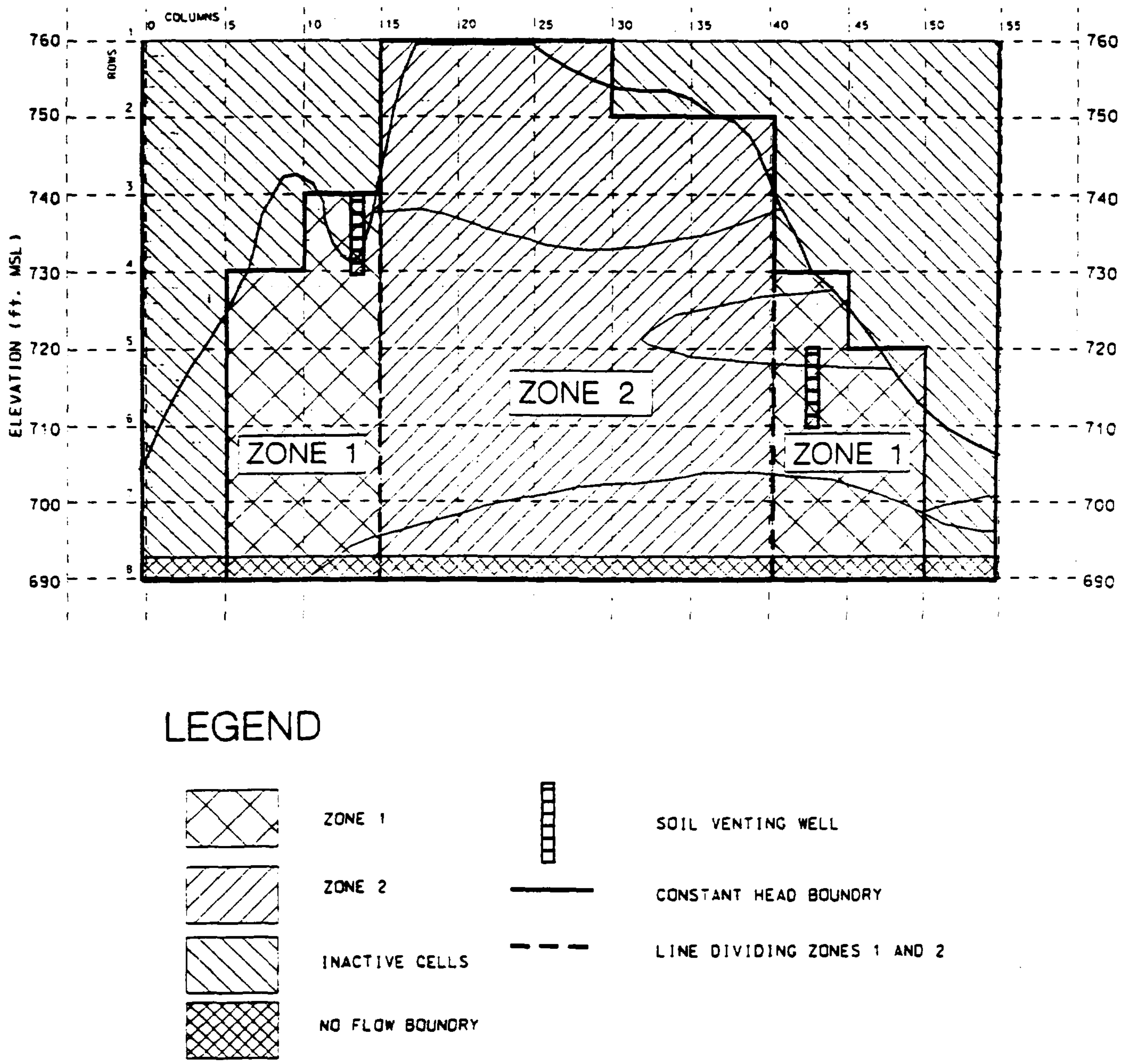
Cut Off $2'' = \frac{2}{12} = -\underline{0.167}$ ft

Instor(?) ... = -120″ = -10′

... CFM = -2138.8 c.ft/day

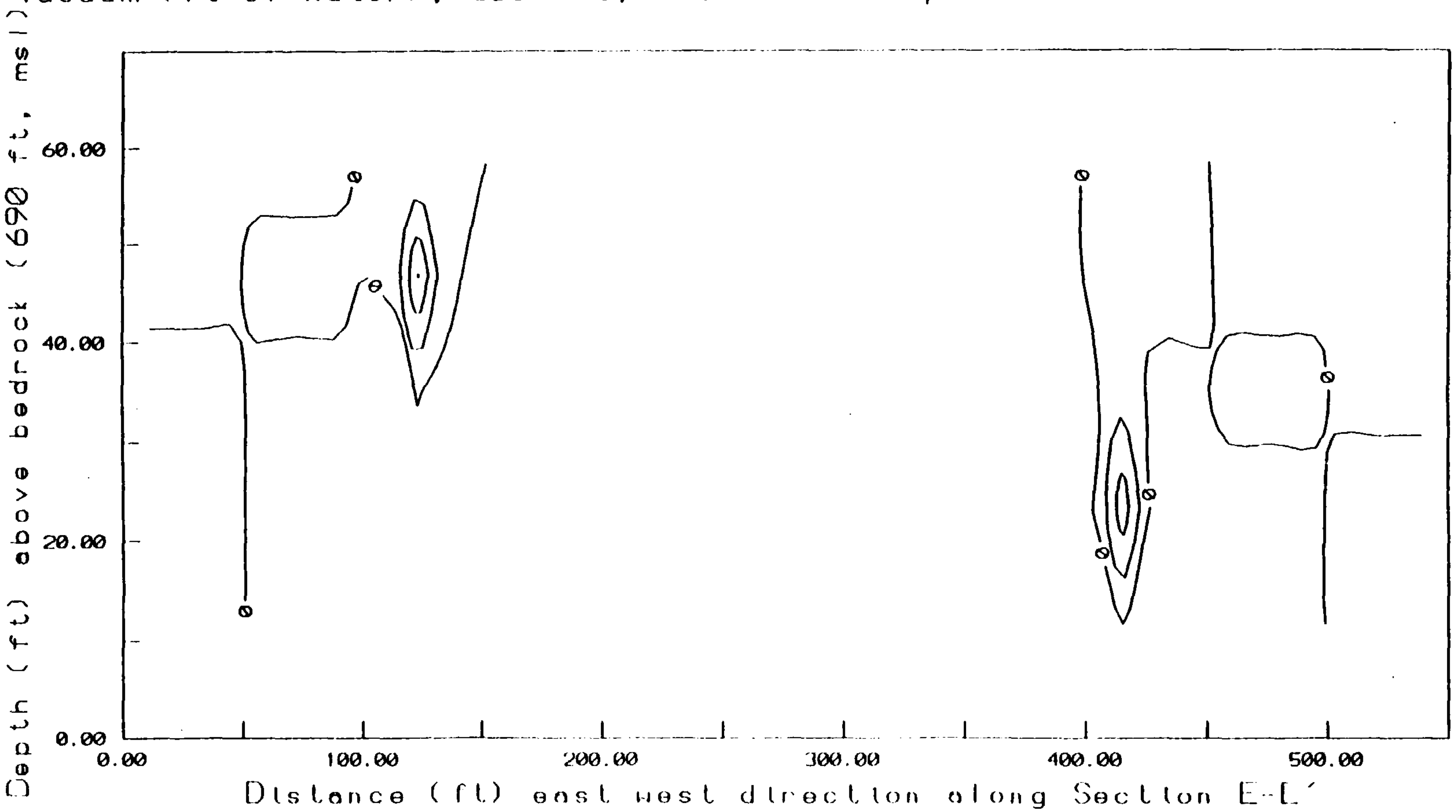
APPENDIX G

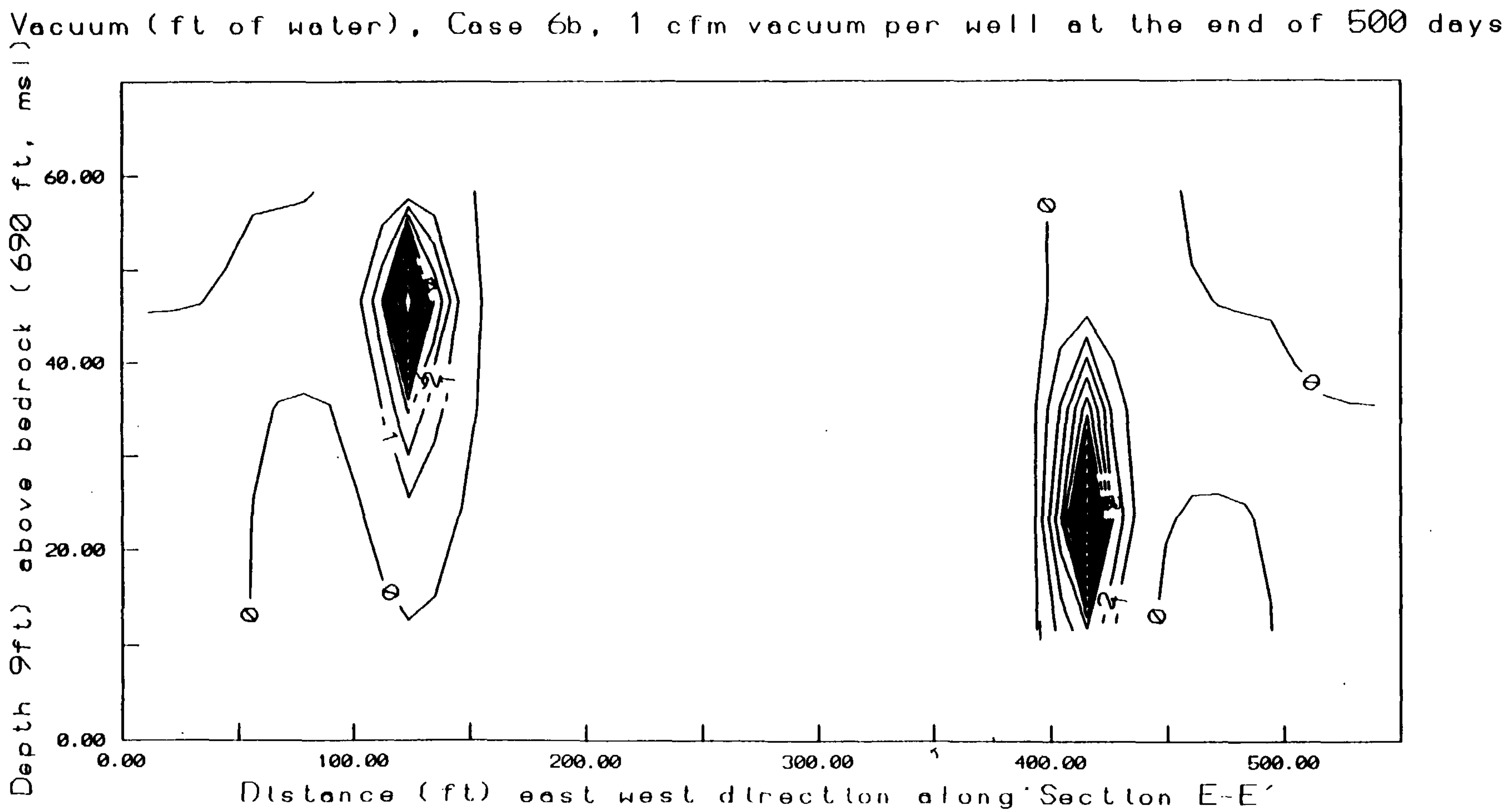
Lateral Pressure Drop From Soil Venting Wells

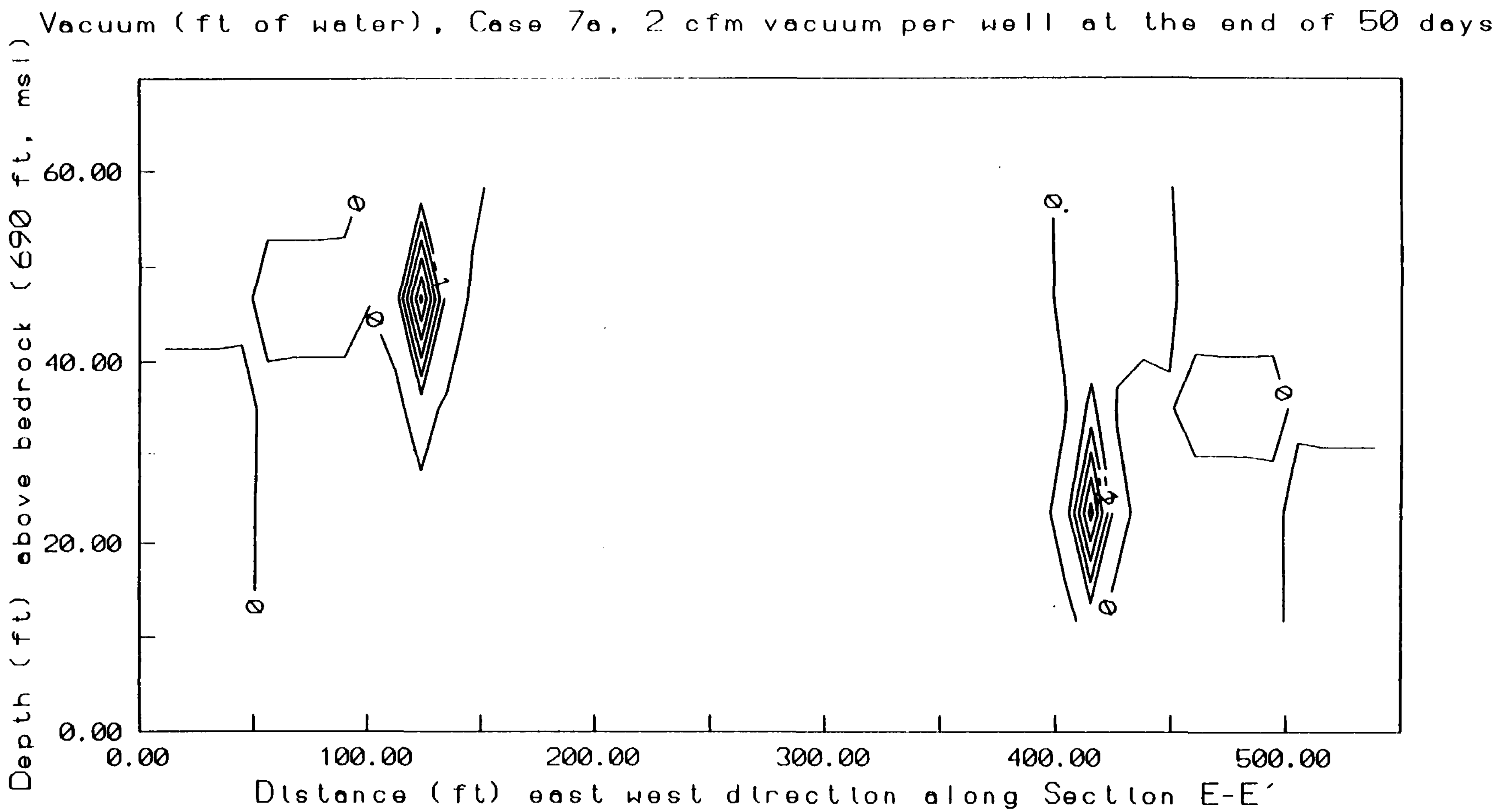


AIR FLOW MODELING FINITE DIFFERENCE GRID SYSTEM

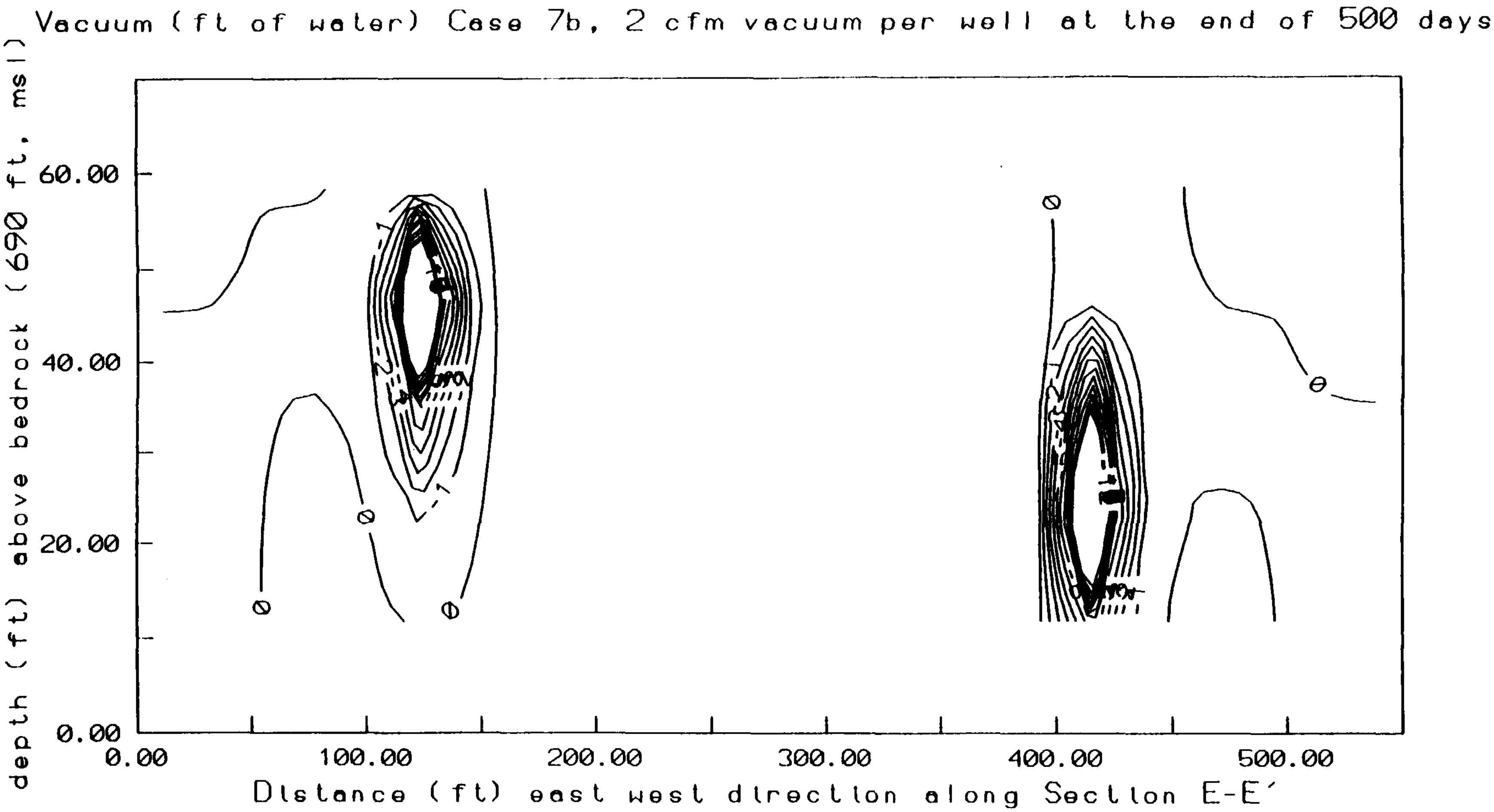
Vacuum (ft of water), Case 6a, 1 cfm vacuum per well at the end of 50 days




Vacuum (ft of water), Case 6b, 1 cfm vacuum per well at the end of 500 days
Depth 9ft) above bedrock (690 ft, msl)
60.00
40.00
20.00
0.00
0.00
100.00
200.00
300.00
400.00
500.00
Distance (ft) east west direction along Section E-E'
0
0
0
0
0
1



Vacuum (ft of water), Case 7a, 2 cfm vacuum per well at the end of 50 days
Depth (ft) above bedrock (690 ft, msl)
Distance (ft) east west direction along Section E-E′
0.00
20.00
40.00
60.00
100.00
200.00
300.00
400.00
500.00



Vacuum (ft of water) Case 7b, 2 cfm vacuum per well at the end of 500 days
depth (ft) above bedrock (690 ft, msl)
60.00
40.00
20.00
0.00
0.00
100.00
200.00
300.00
400.00
500.00
Distance (ft) east west direction along Section E-E'

Analysis of In Situ Vacuum Well Placement Using MODFLOW

ANALYSIS OF IN SITU VACUUM WELL PLACEMENT USING MODFLOW

BACKGROUND

The governing equation for 3-D single phase flow which is solved by MODFLOW using a finite difference method is given by

$$S_s \frac{\partial h}{\partial t} = -\frac{\partial q_x}{\partial x} - \frac{\partial q_y}{\partial y} - \frac{\partial q_z}{\partial z} \qquad [1]$$

where the volumetric flux density in the i-direction is given by

$$q_i = -K_i \frac{\partial h}{\partial x_i} \qquad [2]$$

These equations describe saturated groundwater flow subject to certain assumptions regarding decoupling between saturated and unsaturated zones. The same equations may be used to simulate gas flow in the unsaturated zone under the assumption that: 1) gradients in gas phase density are small compared to the divergence of the gas velocity; 2) effects of gas pressure gradients on water flow by capillary effects are disregarded, e.g., water table upwelling is ignored; and 3) gravitational gas flow is assumed negligible compared to pressure effects. Under these conditions, [1] and [2] will describe gas flow in the unsaturated zone when q_i is taken as the volumetric flux density of gas and other variables are defined as follows

$$h = P/\rho_w g \qquad [3]$$

Gas conductivity = $$K_i = \rho_w g k_{ai}/\eta_a \qquad [4]$$

Specific storage = $$S_s = \mathcal{M} \rho_w g \phi_a/\rho_a RT \qquad [5]$$

where P is the gauge gas phase pressure [F L^{-2}], ρ_w is the density of water [M L^{-3}], g is gravitational acceleration [L T^{-2}], k_{ai} is gas permeability in the i-direction [L^2], η_a is the dynamic viscosity of the gas phase [F T L^{-2}], $\mathcal{M}$ is the molecular weight of gas [M mol^{-1}], ϕ_a is the gas filled porosity [L^3 L^{-3}], ρ_a is the density of gas [M L^{-3}], R is the gas constant [F L mol^{-1} deg^{-1}] and T is Kelvin temperature [deg].

In equation [3], h represents the gas pressure expressed in units of equivalent water height. For example, an absolute gas pressure of 0.8 atm or equivalently a vacuum of 0.2 atm corresponds to a gas pressure head of $h = -2$ m. In equations [4] and [5], K_i and S_s may be referred to as the gas conductivity and specific storage, respectively. It should be noted that alternative means of defining a gas conductivity are possible (using a different reference fluid density) so caution should be used to ensure consistent usage. In [5] it has been assumed that porous medium compressibility is negligible and gas compressibility follows the ideal gas law. For a gas-filled porosity of 0.2 at 10°C, the gas specific storage, S_s, will be approximately 0.02 m^{-1}. For steady state analyses, the value of S_s has no effect on the solution -- it only effects the time required to reach steady state conditions.

An alternative way to write [4] arises by noting that $k_{a_i} = k_{ra}k_i$ where k_{ra} is the gas relative permeability which varies from 0 to 1 and k_i is the intrinsic permeability in the i-direction. Since intrinsic permeability is related to the saturated hydraulic conductivity, K_{sw_i}, as $k_i = K_{sw_i}\eta_w/\rho_w g$ then we may write

$$K_{a_i} = k_{ra}\, K_{sw}/\eta_{ra} \qquad [6]$$

where $\eta_{ra} = \eta_a/\eta_w$. Relative permeability, k_{ra}, will vary from zero when ϕ_a is zero to 1 when ϕ_a is equal to the total porosity, ϕ. The sensitivity of gas relative permeability to gas filled porosity is rather mild at low water contents such that relative permeability generally decreases in a manner roughly proportional to the gas saturation, ϕ_a/ϕ, for gas saturations greater than about 25%. Therefore, to first approximation, gas conductivity may be estimated from hydraulic conductivity if this is known by employing [6] with $k_{ra_i} \approx \phi_a/\phi$. Vertical variations in intrinsic permeability as well as gas relative permeability could be incorporated in the numerical analysis by assigning different gas permeabilities to different layers or areal zones in the model. In practice, the most practical and reliable procedure for determining gas conductivity will be to perform an in situ gas pump test. The pump test data may be analyzed in the same fashion as conventional water pump tests using analytical methods (e.g., Theis or Jacob) or the numerical model may be used to simulate the pump test with conductivity adjusted (by hand or using an automatic algorithm) to fit the observed flow rates and/or observation well pressures.

EXAMPLE PROBLEM

A hypothetical problem was analyzed to demonstrate the use of MODFLOW for designing in situ vacuum extraction systems. The problem involves a domain 250 x 250 m in the areal plane with an unsaturated soil thickness of 20 m (Figure 1). Part of the soil surface over the central 150 x 150 m of the domain is covered with a gas impermeable material and the remainder is open to the atmosphere on an annular strip. Soil properties were assumed to be uniform over the domain with $K_x=K_y=300$ m d^{-1} and $K_z=100$ m d^{-1}. The gas specific storage was taken to be 0.02 m^{-1}. In analysis A, three vacuum extraction wells (W-1, W-2 and W-3) were placed through the covered area and screened over the depth of 15 to 20 m. In analysis B, a fourth well (W-4), screened over the same interval, was placed at a location that would otherwise yield a stagnation point in the gas flow.

Boundary conditions. The lower boundary of the system is the upper limit of the capillary fringe (or to first approximation, the water table). This boundary is assumed initially known from observation well data and is fixed with time. The boundary condition at the bottom is no-flow. Actually, water table upwelling will occur when vacuum wells are pumped. The exact rise in the water table will be equal in magnitude and opposite in sign to the gas pressure head on the lower boundary. Therefore, if a more refined analysis is desired, the location of the lower boundary may be corrected in an iterative fashion. The simplest way to accomplish this would be to reduce the conductivity of the lower blocks in proportion to the fraction which is water-saturated (i.e., if water occupies 0.6 of the block height, reduce K by 0.6).

The lateral boundaries of the system are also treated as no flow boundaries and should be located such that this assumption is met. That is, it is desired that the lateral boundaries be far enough away from the vacuum source that negligible pressure change is propogated to the boundary. If initial simulations indicate this condition is not met, the domain size should be increased.

The upper boundary is the soil surface. Covered portions should be treated as no flow boundaries. Portions which are uncovered should be treated as constant pressure boundaries. Specifically, h=0 is assumed on atmospheric boundaries.

Vacuum wells are treated as normal pumping wells in MODFLOW with the total gas flow rate prescribed [M^3 T^{-1}]. Note that withdrawal rates have a negative sign. If the well bore vacuum is known rather than the withdrawal rate, then the latter should be guessed and several trial simulations performed until the correct flow rate is obtained. In the present case, the flow rates at wells W-1, W-2 and W-3 were each assumed to be 10,000 m^3 d^{-1}.

Injection wells are treated as interior prescribed pressure nodes. Specifically, they are treated as nodes with a constant pressure of h=0 on the screened portion. Well W-4 is treated in this fashion.

Model results. Contour plots of the steady state gas pressure head distributions for problems A and B are shown in Figures 2 and 3, respectively. In designing the vacuum system, it is desired to have gas flow directed through the hydrocarbon contaminated soil with no stagnant zones. Placement, screening interval and pressure of vacuum wells; location and screening interval of intake wells; and extent of surface cover may be manipulated to achieve suitable system operating conditions. Inspection of the pressure field within the zone of contamination may be used to judge the design in an ad hoc fashion. A more quantitative and accurate approach would be to perform an analysis of travel time distributions through the plume with the objective of designing the system to minimize the mean travel time and the travel time variance. Such an analysis could be performed using a program such as GWPATH which interfaces with MODFLOW to compute travel times on selected streamlines. Starting points for the travel time analysis should be selected on start at the plume boundary and at injection wells if they occur such that streamtubes of equal total flow are analyzed.

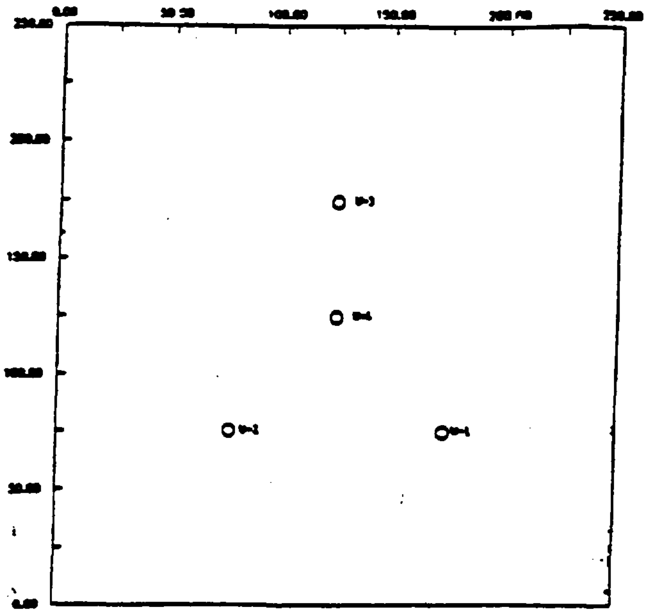


Figure 1. Areal view of hypothetical gas venting problem.

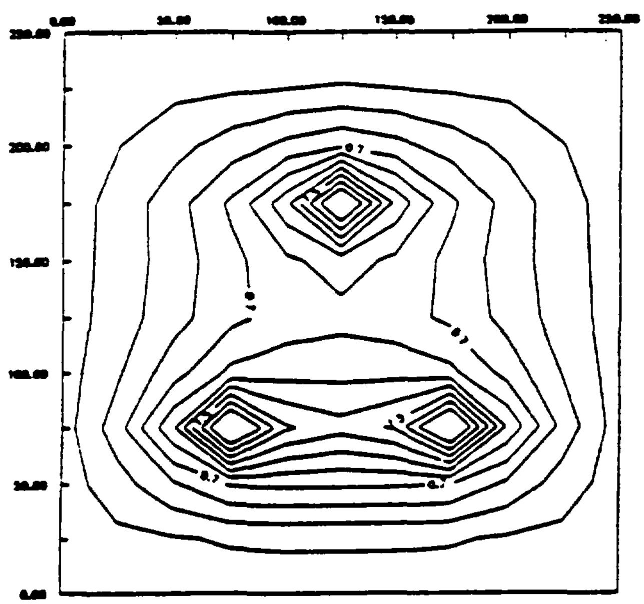


Figure 2. Contour plot of gas pressure heads (h, meters) without injection well W-4.

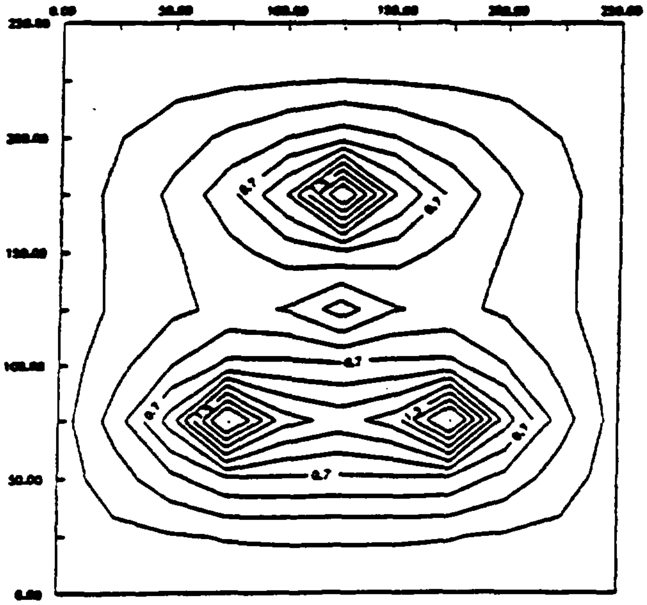


Figure 3. Contour plot of gas pressure heads (h, meters) with injection well W-4.

APPENDIX H

HyperVentilate Information Package

SKINNER LANDFILL
SVE SYSTEM FEASIBILITY INVESTIGATION
USING HYPERVENTILATE DECISION-SUPPORT SOFTWARE

HyperVentilate was the primary tool used in evaluating the feasibility of SVE at the Skinner Landfill. This interactive, software guidance system is approved by, and available from the USEPA. The two applications for HyperVentilate were intended to determine the following:

1. To determine if soil venting is appropriate at a site
2. To approximate the minimum number of extraction wells anticipated to be needed

AN EVALUATION OF SVE WELLS INSTALLED WITHIN THE LAGOON BOUNDARY

A. Lagoon Lithology

1. Based upon 15 test boring (prior Rust investigation)
2. Sediments are Clay to Silty-Clay Soils
3. Static Water Level at 18 to 27 feet below grade

Input data for HyperVentilate Model:

Type of Soil	Silty Clay
Permeability Range (darcy)	0.01 - 0.0001
Well Radius	4 "
Radius of Influence	30 '
Interval Thickness	10 '
Temperature	16 degrees C
Composition of Contaminant	BETX (for model application)
Estimated Spill Mass	26,900 kg
Desired Remediation Time	547.5 days (1.5 years)
Contaminant Distribution: Radius of Influence Interval Thickness Average Concentration	 20,000 ft^2 10 ft 2,666 mg/kg
Design Vacuum	120 " H_2O

Based upon the given input parameters, the Hyperventilate Software indicated that a minimum of 84 SVE wells would be required to remediate the buried lagoon contaminants. A number of this magnitude is not practical for a cost-effective soil venting system.

SKINNER LANDFILL
SVE SYSTEM FEASIBILITY INVESTIGATION
PERIMETER SOIL EVALUATION
USING HYPERVENTILATE DECISION-SUPPORT SOFTWARE

HyperVentilate was used in evaluating the feasibility of SVE in the perimeter soils at the Skinner Landfill. This interactive, software guidance system is approved by, and available from the USEPA. The two applications for HyperVentilate were intended to determine the following:

1. To determine if soil venting is viable and effective in the perimeter soils.
2. To approximate the minimum number of extraction wells anticipated to be needed

AN EVALUATION OF SVE WELLS INSTALLED WITHIN THE PERIMETER SOILS

A. Perimeter Soil Lithology

1. Based upon 7 perimeter test borings (Rust supplimental investigation)
2. Sediments are Sandy Loam Soils
3. Static Water Level at 18 to 27 feet below grade

Input data for HyperVentilate Model:

Type of Soil	Sandy Loam
Permeability Range (darcy)	0.05 - 0.005
Well Radius	4 "
Radius of Influence	30 '
Interval Thickness	10 '
Temperature	16 degrees C
Composition of Contaminant	BETX (for model application)
Estimated Spill Mass	26,900 kg
Desired Remediation Time	365 days
Contaminant Distribution: Radius of Influence Interval Thickness Average Concentration	 20,000 ft^2 10 ft 2,666 mg/kg
Design Vacuum	120 " H_2O

Based upon the given input parameters, the Hyperventilate Software indicated that a minimum of 32 SVE wells would be required to contain the migration of contaminants through perimeter soils A number of this magnitude is not practical for a cost-effective soil venting system.

Rust Environment & Infrastructure

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